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Sewage Research

Time and Rate of Sludge Digestion, and Their Variation with Temperature

By Gordon M. Fair and Edward W. Moore

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A recent paper by Heukelekian[1] in This Journal calls attention to the fact that the effect of temperature on rate or time of digestion of sewage solids is still a matter for debate, especially in the range between thermophilic temperatures (50–55° C.) and non-thermophilic temperatures (28° C. and below). Heukelekian's work shows also that proper seeding of solids to be digested demands the use of a seeding sludge produced at the temperature of digestion, a fact previously recognized by the authors,[2] and, for thermophilic digestion, by Rudolfs.[3] Keefer and Kratz[4] have found that digestion at 37° is slightly more rapid than at 28° C., but the seeding sludge used by them was apparently not produced at the temperature of digestion. In an earlier issue of This Journal the authors[5] express the rapidity with which sludge digests as a numerical "velocity constant," thus applying to sludge digestion the principles of the kinetics of chemical reactions. It was found that the rate-constant increased slightly from 25° to 40° C., for properly seeded digestion (Series III) of fresh solids. While this rate-constant is not strictly proportional to time of digestion unless the quantities of gas produced are the same at every temperature, the time may be readily computed from it.

It is the purpose of this paper to attempt to summarize the experience regarding time of digestion in relation to temperature; to include the authors' previous results, but expressed in this case on the basis of digestion time; and to discuss certain difficulties in estimating digestion time for batch experiments.

Estimating Time of Digestion.—Few authors agree on the method of arriving at a value for digestion times, and it is well to emphasize that there is, strictly speaking, no one time of digestion at a given temperature. The rate at which digestion proceeds is controlled by many variables, chief of which are the nature (biological as well as chemical) of the seeding material, and the nature of the material to be digested. It is therefore unreasonable to presume that two investigators working at the same temperature, but with different materials, will find the same time of digestion

Even two different "catches" of fresh solids from the same source but taken at different seasons of the year, on different days or even at different hours of the day, should not be expected to digest at the same rate when held at the same temperature, unless the quality of the sewage at the source is very uniform (see Keefer and Kratz[4]).

It appears hopeless, therefore, to obtain a satisfactory comparison of the digestion times obtained by different workers, except on a purely relative basis, that is, by expressing the times at various temperatures in terms of the time at some standard temperature. If this is done, the results obtained in different tests may be compared with some success in respect to the effect of temperature on digestion time. It makes but little difference what temperature is chosen as the reference. Temperatures of 20° to 25° C. are reasonable in view of the fact that much is known about digestion at these values; but any others might be selected.

In estimating the time taken for batch digestions it is possible to predicate digestion time on two factors that may measure inadequately, if not incorrectly, the effect of temperature on digestion time. The first factor inheres in the common practice of cutting off experiments when the rate of gas production reaches a certain fixed value. If the cumulative gas-evolution curves for several experiments are studied, it will be found that some rise sharply and flatten out suddenly as the total yield is reached, whereas others rise only slowly, and the flattening off is gradual. Cutting off experiments when a fixed rate of production is attained favors the latter type—that is, makes the digestion time appear shorter than is actually the case. This difficulty may be avoided by determining the time for cutting off each experiment, not as a fixed rate is experienced, but as a fixed percentage of the maximum rate of production observed for the particular experiment is obtained. This percentage method would appear to furnish a fairer comparison of the two types of digestion. The second factor inheres in the practice of comparing times of digestion for different temperatures on the basis of 90 per cent of total gas yield at the temperature in question. This percentage is assumed to represent a practical limit of digestion. However, the work of Heukelekian,[1] of Keefer and Kratz,[4] and of the authors,[5] shows an appreciable variation in the total yield of gas from the same quantity of fresh solids digested at different temperatures. To compare the times on the basis of 90 per cent of these various individual totals would appear to be unfair. The same quantity of solids may produce 720 cc. of gas at 28° C. and 800 at 42° C. (Heukelekian,[1] Series III). But the sludge digested at 42° C. has presumably been subjected to the same degree of decomposition when it has produced 720 cc. of gas, as the sludge digested at 28° C. when it has reached its limit of yield at 720 cc. If the results of a series of digestions of the same material at different temperatures are to be compared with respect to time

on the basis of 90 per cent of gas production, the lowest 90 per cent value in the series should seemingly be employed as the value of reference. This procedure should give a fair value for time of digestion at each temperature and furnish a comparable measure of the effect of temperature on the speed of digestion.

Observed Time of Digestion.—An attempt is made to assemble in this paper the information on digestion time available in the literature. In order to make the results comparable, a temperature of 25° C. has been chosen as a convenient reference point. Wherever possible, the times have been recalculated in accordance with the ideas previously discussed. Unfortunately, this is impossible for many of the values, since the data published are inadequate. A summary of the sources and methods of computation of the data follows.

The authors' own values were taken from cumulative gas production plots for fresh solids, seeded with material that had been adapted to the temperatures used by two previous runs. The time of digestion was read at the lowest observed 90 per cent value of gas yield for the series. The recent results of Heukelekian[1] for Experiments 3 and 4 were transformed to relative values by the use of an estimated time of 12 days for digestion at 25° C. The data published are not sufficient to recalculate them on the basis of equal gas production. Heukelekian's[6] earlier values for high temperatures were transformed by taking the digestion time to be 30 days at 25° C. The time at 28° C. was cited as 25 to 30 days, and at 22° as 35 days. The results given by Keefer and Kratz[4] permitted estimation of time of digestion for equal gas production. A total production of 720 cc. was taken as a good approximation of 90 per cent digestion at 28° C. The 25° times were estimated to be 24 days for Experiments 1 and 2, and 51 days for Experiment 3. Incidentally, the work of Keefer and Kratz shows the variability in absolute time which occurs even when solids from the same source are used. Values taken from Imhoff's "Taschenbuch"[9] cover the range below 25°. The work of Rudolfs[7] was recalculated on the basis of interpolated times for 25° of 127 days for untreated sludge and 98 days for limed sludge. There was no seeding of the sludge, so that the results above 25° are probably not useful in comparative studies. Some unpublished work by G. M. Fair[10] and by H. G. Baity[11] is also included. These experiments employed seeding sludge, but not material produced at the temperature of incubation.

The results of these computations are given in Table I and have been plotted in Figure 1 to show the relative time of digestion at various temperatures. An attempt has been made in Figure 1 to draw a representative or average line, bearing in mind the conditions under which the results were obtained. There are a number of different possibilities, but it seems to the authors that the line, or rather lines, drawn by them, al-

TABLE I

TIME AND RATE OF DIGESTION RELATIVE TO TIME AND RATE AT 25° C.

Authors	Temperature, ° C.	Relative Time	Relative Rate
Fair and Moore[2]	25	1.00	1.00
Fair and Moore[2]	30	0.86	1.16
Fair and Moore[2]	35	0.82	1.22
Fair and Moore[2]	40	0.80	1.25
Fair and Moore[2]	45	0.76	1.32
Fair and Moore[2]	50	0.61	1.64
Heukelekian[1]	28	0.75, 0.83	1.33, 1.20
Heukelekian[1]	33	0.83, 0.67	1.20, 1.49
Heukelekian[1]	37	0.75, 0.83	1.33, 1.20
Heukelekian[1]	42	0.92, 0.92	1.09, 1.09
Heukelekian[6]	50	0.47	2.13
Heukelekian[6]	55	0.37	2.70
Heukelekian[6]	60	0.40	2.50
Heukelekian[6]	65	0.90	1.11
Heukelekian[6]	70	0.87	1.15
Keefer and Kratz[4]	28	0.91, 0.96, 0.96	1.10, 1.04, 1.04
Keefer and Kratz[4]	37	0.68, 0.83, 0.82	1.47, 1.20, 1.22
Imhoff[9]	25	1.00	1.00
Imhoff[9]	20	1.45	0.69
Imhoff[9]	15	2.22	0.45
Imhoff[9]	10	3.89	0.26
Imhoff[9]	5	7.78	0.13
Fair[10]	10	5.00	0.20
Fair[10]	20	1.40	0.71
Fair[10]	25	1.00	1.00
Fair[10]	30	0.60	1.67
Fair[10]	35	0.80	1.25
Baity[11]	15	1.82	0.55
Baity[11]	20	1.27	0.79
Baity[11]	25	1.00	1.00
Rudolfs[7] Untreated Sludge	10	2.84	0.35
Rudolfs[7] Untreated Sludge	18	1.58	0.63
Rudolfs[7] Untreated Sludge	24	1.12	0.89
Rudolfs[7] Untreated Sludge	29.5	0.48	2.08
Rudolfs[7] Untreated Sludge	35	0.70	1.43
Rudolfs[7] Limed Sludge	10	3.32	0.30
Rudolfs[7] Limed Sludge	18	1.53	0.65
Rudolfs[7] Limed Sludge	24	1.10	0.91
Rudolfs[7] Limed Sludge	29.5	0.55	1.82
Rudolfs[7] Limed Sludge	35	1.10	0.91

though speculative, hold some promise of confirmation. The observed values seem to arrange themselves along two separate lines, one for thermophilic and the other for non-thermophilic digestion. There appears to be a zone of discontinuity between the two types of digestion. Thermophilic digestion seems to come into play at about 42° C., and each proc-

ess apparently has its own minimum, that for non-thermophilic digestion lying somewhere between 30° and 35° C., and that for thermophilic digestion near 55° C. The range 35° to 42° C. seems to represent a region in which both thermophilic and non-thermophilic organisms work at a disadvantage. Results in the neighborhood of the non-thermophilic optimum are somewhat conflicting. Even the results of individual workers do not agree well. The values by Rudolfs and Fair at 30° show a marked deviation from the average curve, but this is probably because the experiments were either unseeded (Rudolfs) or seeded with material produced at some other temperature (Fair). It may be that this temperature represents an op-

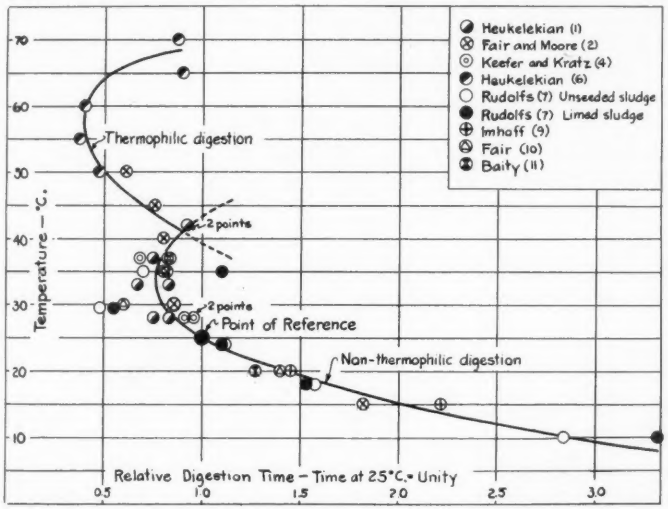

FIG. 1.—Relative Digestion Time of Plain-Sedimentation Sludge Digested at Temperatures of 10° to 70° C. Digestion Time Is Referred to Time Required at 25° C.

timum for material not properly seeded. For non-thermophilic conditions, the time required for digestion increases rapidly as temperatures fall below 20° C.

Rate of Digestion.—The reciprocal of the relative time of digestion is a measure of the over-all rate of digestion and as such should and does reflect the basic chemical concepts of reaction velocity. These furnish a second approach to the evaluation of the effect of temperature on the digestion of sewage solids. This approach was taken by the authors in a previous paper[5] and is much the same as that followed by Theriault[8] in his studies of biochemical oxygen demand. The same concepts have also

been applied by Crozier and others to a host of other biochemical processes, many of which are even more complex than sludge digestion. References to this work will be found in the authors' original paper.[5]

In any complex system of reactions, the slowest one exerts the controlling influence, and the effect of temperature on this controlling reaction determines the influence of temperature on the entire process. The effect of temperature on any chemical reaction within the temperature range in which the reaction can go on may be expressed by the Arrhenius equation as follows:

$$\log K_T - \log K_0 = \frac{\mu}{2.3026\ R}\left(\frac{1}{T} - \frac{1}{T_0}\right)$$

where K_T and K_0 = constants expressing, respectively, the velocity of the reaction at the absolute temperature T (273.1 + t° C.) and the absolute reference temperature T_0 (273.1 + t_0° C.).

R = the gas constant = 1.9885 calories

μ = the temperature constant, or characteristic, of the reaction.

Obviously this is the equation of a straight line:

$$y - y_0 = C\,(X - X_0)$$

The origin of this line is at y_0 (logarithm of the reaction constant at reference temperature t_0° C.) and X_0 (reciprocal of absolute temperature corresponding to t_0° C.); the slope of the line is $C = \frac{\mu}{2.3026\ R}$. The line is best plotted therefore by choosing a logarithmic scale for the ordinate (ratio of reaction constants) and an arithmetic scale for the abscissa (reciprocal of absolute temperature). A straight-line plot should be obtained within the range in which a particular reaction exerts the controlling influence.

This method of reasoning may be applied to the data at hand. As previously indicated, the reciprocal of the relative time of digestion as computed in this paper may be taken as equal to the relative over-all rate of digestion. These relative rates have been calculated and are included in the accompanying table. They are shown graphically in Figure 2, in which the abscissa is divided into intervals determined by the reciprocal of the absolute temperature, and the ordinate into logarithmic intervals of relative rate. By this procedure the actual relative rates may be plotted against the actual temperatures, but the effect is really that of a plot of the logarithm of the rate *versus* the reciprocal of the absolute temperature.

Figure 2 shows a number of interesting things concerning the rate of digestion as influenced by temperature. From 10° to 28° C., the change in rate caused by temperature appears to agree well with the law of Ar-

rhenius, as evidenced by the straight-line fit of the data. Calculated on this basis, the value of μ in this range is approximately 12,000. Within this range, therefore, there seem to be no disturbing factors. The rate of the process is controlled by the rate of the slowest reaction, and the rate of this reaction changes with temperature substantially in accordance with chemical laws. At about 28° C. a marked deviation from this behavior is observed. The increase in rate becomes appreciably less than that demanded by the law of Arrhenius, and a little further on, at about 33–35°, the increase in rate ceases altogether. Beyond this region a decrease in

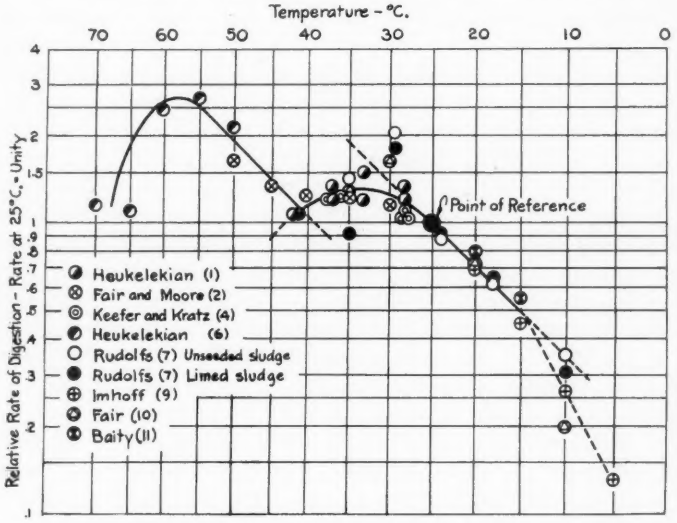

FIG. 2.—Relative Digestion Rate of Plain-Sedimentation in Sludge Digested at Temperatures of 5° to 70° C. Over-all Rate Is Referred to Over-all Rate at 25° C. Vertical Scale Is Logarithmic. Horizontal Scale Is Based on the Reciprocal of the Absolute Temperature (°C. + 273.1).

rate occurs which continues up to about 42° C. In the range 28° to 42° C., therefore, digestion rate is apparently no longer governed directly by straightforward chemical phenomena. Some other influence comes into play, disturbing the progress of the reaction and ultimately hindering it so much that the rate decreases at higher temperatures. One possible explanation that suggests itself is that temperatures in this range are progressively more unfavorable to the existence of the non-thermophilic organisms which do the work of digestion below 28°. Thus any increase in the velocity of the chemical reactions, by which the bacteria sustain life and convert the solids into gas and residue, is compensated and ulti-

mately turned into a net decrease in activity by the adverse effect of the higher temperatures on the bacteria themselves. According to the observations so far reported, the maximum rate for non-thermophilic digestion appears to be somewhere between 33° and 35° C., although, as Heukelekian[1] has shown, the differences in this region are small and still in doubt. This is probably the reason why so much difference of opinion exists as to the non-thermophilic optimum. The differences are apparently less than the variation observed in individual experiments.

With properly acclimatized seeding material, a new factor is introduced at about 42° C. It seems probable that thermophilic organisms predominate at this temperature. From this point on up to 55° C., the increase in rate with temperature again seems to follow Arrhenius' law, and it is interesting to note that the value of μ appears to be the same within the limit of accuracy as that for non-thermophilic digestion. Chemists regard the value of μ as an indication of the type of chemical reaction involved, since it has been found that reactions of the same type show the same value of μ (See Fair and Moore,[5] p. 596). It seems likely, therefore, that the slowest, or controlling, reaction is the same, or of the same nature, in thermophilic digestion as it is in non-thermophilic digestion. Beyond 55° the rate of thermophilic digestion drops in much the same manner as does the non-thermophilic rate at 33°. The explanation for this may be that temperatures above 55° are unfavorable to the new group of organisms that work within the thermophilic range. The studies of Heukelekian[6] indicate that the thermophilic optimum lies near 55° C.

It may be of interest to note that the observed rates for the range 28° to 42° lie between the rates expected according to Arrhenius' law for thermophilic and for non-thermophilic digestion. At 35° the observed rate lies almost midway between the two expected rates indicated by the dotted lines. This zone may, therefore, represent a region of transition from non-thermophilic to thermophilic digestion. Possibly both types of organisms are active within it, but operating under more or less adverse conditions. This idea was not borne out, however, in Experiment VII

TABLE II

DIGESTION OF SLUDGE AT 50° AFTER SEEDING WITH SLUDGE PRODUCED AT VARIOUS TEMPERATURES

Temperature of Production of Seeding Sludge, ° C.	Time in Terms of Time with 50° Sludge	Rate in Terms of Rate with 50° Sludge
25	1.20	0.83
30	1.36	0.74
35	1.64	0.61
40	1.35	0.74
45	0.84	1.19
50	1.00	1.00
60	1.07	0.93

of the authors' work[5] in which solids were seeded with material produced at 25°, 30°, 35°, 40°, 45°, 50° and 60°, and all mixtures digested at 50°. The relative times and rates observed in this experiment are shown in Table II.

According to these results, sludge produced at 25° C. was more effective as seeding material than that produced in the intermediate range from 30° to 40° C. It seems, therefore, that factors other than the flora of the sludge, such as the buffering effect of the seeding sludge, may be of moment. Contrary to what has been said are also the authors' findings that the digestion of activated sludge showed no drop in rate in the intermediate range. The rate of digestion increased along the whole way from 25° to 50° C.; in other words, the time decreased. This increase in rate is shown in the authors' original paper in terms of the rate-constant.[5] Incidentally, it is possible to approximate the curve running from 25° to 40° C. by a straight line. This was done by the authors in their original paper but appears to be less desirable in the light of the present study of a larger mass of data. It stands to reason, however, that further studies may lead to renewed modification of statement.

Below 10° C., there is some evidence, though slight, of an abrupt change in the line representing change of rate with temperature. The slope of the line becomes much greater, the value of μ changing from 12,000 to 23,000. Such breaks are frequently observed in the results of Crozier and other workers on the effect of temperature on the rates of biological processes. Breaks of this kind indicate that some reaction with a high temperature characteristic (μ) is the slowest or controlling member of the chain at low temperatures, but that the rate of this reaction is increased so rapidly with temperature that it soon ceases to be the slowest. It is superseded at some critical point by another member of the chain, whose increase in rate with temperature (μ) is lower. This reaction then becomes the slowest or controlling member of the chain.

In digesting solids on a practical scale, it would seem as though little would be gained by raising the temperature above 28° C. and nothing by increasing the temperature above 33°, unless it was intended to go all the way to 50° or 55° C. in order to take advantage of thermophilic digestion. So far as present information permits drawing a conclusion, this would not seem to be true of the digestion of activated sludge, which appears to be benefited continuously up to temperatures of 55° C. It must be remembered at all times that the rate in batch experiments is by no means the same as the rate in a continuous addition process. The latter rate may theroretically approach the maximum rate of digestion observed in a batch experiment. Whether a change of temperature would affect the rate of a continuous addition process in the same way as it influences the over-all or average rate of a batch process, as here computed, remains a matter for speculation, until further information becomes available.

Summary and Conclusions

This attempt to convert to a comparable basis the data of various authors on the effect of temperature on the time necessary for digestion has necessitated making certain assumptions regarding data for which the necessary information was incomplete. It is hoped that the various investigators themselves will supply this information and, if necessary, revise the position of their own values on the curves here suggested. Subject to such revisions, the following conclusions may be advanced at this time:

1. With regard to the effect of temperature on batch digestion of sewage solids, three or possibly four distinct zones of activity seem to be indicated as follows:

   (1) Thermophilic zone—above 42° C.
   (2) Intermediate zone—28° to 42° C.
   (3) Temperate zone—below 28° C. and possibly above 10° C.
   (4) Cryophilic zone (possibly)—below 10° C.

2. In two of these zones (1 and 3) and a possible third (4), the digestion process seems to follow ordinary chemical laws, the time decreasing and the rate increasing as demanded by the law of Arrhenius.

3. In the intermediate zone (2), chemical laws are apparently not followed, and there is some evidence of a disturbing factor, possibly the unfavorableness of these temperatures to the bacteria themselves.

4. In agreement with Heukelekian,[1] the optimum for non-thermophilic digestion is set tentatively at about 33° C., although in this region differences of a few degrees produce but little change in digestion time.

5. The behavior of activated sludge may not be in all ways similar to that of plain-sedimentation solids.

Addendum

Dr. Mohlman has kindly called the authors' attention to the fact that they have overlooked the digestion studies of Zack and Edwards.[12] Since it is too late to show on the curves the values obtained by these workers, they are appended herewith in numerical form.

Using the principles for calculation laid down in the body of the paper, the values obtained by Zack and Edwards reduce to the following:

Type of Digestion	Temperature °C.	Relative Time Observed	Relative Time from General Curve
Seeded Fresh Solids	20	1.45	1.4
	37	0.72	0.8
Unseeded Fresh Solids	15	2.06	2.0
	20	1.43	1.4
	25	1.00	1.0
	37	0.63	0.8

The basic gas production for seeded fresh solids was taken as 450 liters per kilogram of volatile solids; that for unseeded fresh solids, as 340 liters per kilogram. The time estimated for digestion of seeded fresh solids at 25° C. was 27.5 days. It will be seen that with the exception of unseeded digestion of 37°, the values agree well with the averages suggested by the authors.

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The Digestion of Garbage with Sewage Sludge

BY C. E. KEEFER AND HERMANN KRATZ, JR.

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At the present time several methods are available for the disposal of municipal garbage. Of these the two that have the widest applicability are incineration and reduction. Both of these processes are alike in one characteristic: the highly complex organic materials are broken down into a stable residue. As this same broad principle of the degradation of organic matter is frequently applied in the treatment of sewage, where substances decompose biologically, it is logical to assume that some of the methods used at a sewage works for the stabilization of organic solids might also be employed for the disposal of garbage.

The treatment of sewage solids has been successfully accomplished for a number of years in septic, Imhoff and separate sludge tanks with the formation of stable end products, which are often used advantageously. It was thought that perhaps the organic materials in garbage were such that they would readily decompose when mixed with sewage sludge. The idea of the digestion of garbage with sewage sludge is by no means new. The method was used with success at Lebanon, Pa.,[1] where ground garbage was added to the sewage and then treated in an Imhoff tank. No published records are available, however, regarding many details of the process, such as the time required to digest the material, the optimum pH value at which digestion takes place, the character and quantity of gases produced and other such important matters. In order to answer some of these questions a series of laboratory experiments have been conducted at the Baltimore sewage works. The observations indicate that garbage digests readily when mixed with equal weights of raw sewage sludge (dry volatile solids basis) with a total gas production equal to, if not greater than, the gas produced by digesting sewage solids alone. All of the investigations, including those still under way, indicate that a mixture of equal weights of sludge and garbage, properly seeded, digests within 30 to 40 days when incubated at 28° C.

Preliminary Experiments

Two series of experiments have been conducted up to the present time. The first series, which was preliminary in character, was made in order to determine whether the organic materials in garbage would digest anaerobically when mixed with digested sewage sludge. The garbage was collected at the garbage incinerator in Baltimore, and was carefully selected in order to have a sample as representative as possible. The sample for digestion was ground into a pulp by means of a food chopper.

The sludge was obtained at the Baltimore sewage works, where the sewage is treated from a separate system of sewers. The raw sludge used was drawn from one of the preliminary settling tanks, and was some 5 or 6 days old. The digested material, which is estimated to have been about 50 days old, was collected from a sludge tank heated to about 85° F. The characteristics of the materials are given in Table I. The quantity of volatile solids in the garbage, which amounted to 87.1 per cent, was considerably higher than in the undigested sludge. The ether-soluble matter in the two materials was about the same. The pH value of the garbage was 5.1, and that of the undigested sludge was 4.9. The digested sludge was well decomposed as is apparent by its volatile solids content of 50.5 per cent.

TABLE I

CHARACTERISTICS OF GARBAGE, UNDIGESTED AND DIGESTED SLUDGE USED

Material	Volatile Solids, %	Ether-Soluble Matter, %	Moisture, %	pH
Garbage	87.1	13.5	84.8	5.1
Undigested Sludge	70.4	13.9	89.5	4.9
Digested Sludge	50.5	7.3	87.9	6.9

When the work was begun, it was not known whether garbage could be digested when seeded with ripe sewage sludge. It was, therefore, decided to combine the materials in various proportions, and add raw sludge to some of the mixtures. As indicated by Table II six different mixtures were used. One of these, which contained 2 parts of raw and 1 of digested sludge, served as a control. In two of the mixtures equal weights of

TABLE II

CHARACTERISTICS OF MATERIALS AT BEGINNING AND END OF DIGESTION PERIOD

Proportions of Materials Mixed[a]			Beginning of Test				End of Test			
Digested Sludge, Parts	Raw Sludge, Parts	Garbage, Parts	Volatile Solids, %	Ether-Soluble Matter, %	Moisture, %	pH	Volatile Solids, %	Ether-Soluble Matter, %	Moisture %	pH
1	2	0	61.4	11.6	94.7	6.8	51.1	6.0	96.0	7.2
1	½	½	60.3	9.8	94.1	7.2	50.7	6.9	95.3	7.2
1	1	1	64.6	9.5	94.0	7.0	52.6	4.7	95.8	7.4
1	0	1	61.8	6.6	93.5	7.2	52.6	4.9	95.3	7.3
1	0	2	68.4	7.2	93.1	7.2				
1	0	3	71.5	8.8	92.9	7.2				

[a] The proportions were based on the weight of dry volatile solids present.

[b] Analyses were not made as materials were only partly digested at end of experiment.

garbage and raw sludge (dry volatile solids basis) were seeded with digested sludge. The other three mixtures contained from 1 to 3 parts of garbage to one part of digested sludge but with no raw sludge present. Duplicate samples of all of the materials were prepared for observation

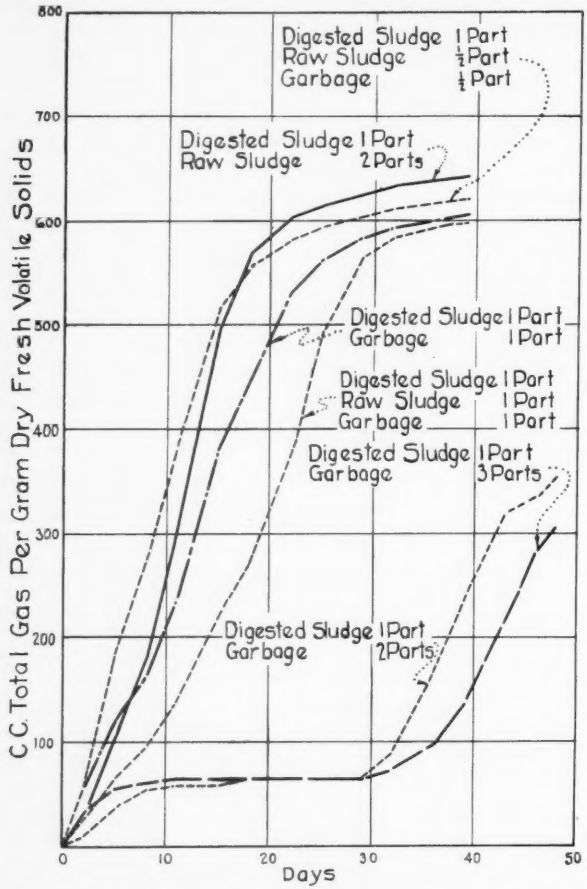

FIG. 1.—Total Gas Production from Garbage and Raw Sludge Seeded with Digested Sludge. Incubation Temperature 28° C.

and analysis. Ten pounds of each of the mixtures were placed in a 5-gal carboy, and incubated at 28° C. ±1°. At the beginning of the experiment the pH values of all of the materials, which were acid, were increased to 6.8–7.2 by means of lime. From time to time small additions of lime were made to keep the material at these pH values.

The progress of digestion was observed by determining the quantity and the character of gas produced. These observations were made at intervals of from 2 to 5 days or less frequently, depending on the volume of gas evolved. The quantities of total gas and methane produced per gram of fresh dry volatile solids are shown in Figures 1 and 2. The amounts indicated in these figures, together with those in the other figures and tables, are average values of the two sets of tests made on the dupli-

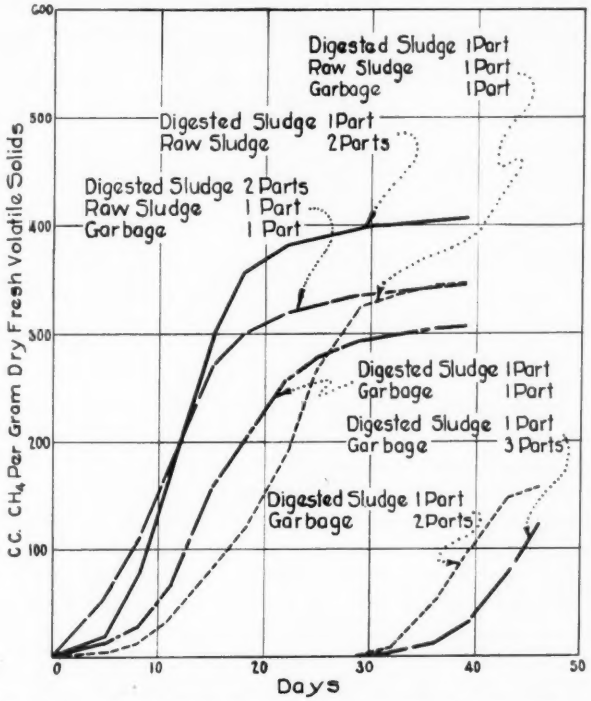

FIG. 2.—Methane Production from Garbage and Raw Sludge Seeded with Digested Sludge. Incubation Temperature 28° C.

cate group of materials. All gas volumes have been reduced to 0° C. at a pressure of 760 mm. of mercury. In every instance the results obtained from the duplicate set of tests compared favorably with one another. The control, which contained 1 part of digested and 2 parts of raw sludge, had the highest total gas and methane production, the total gas amounting to 640 cc. per gram of fresh dry volatile solids and the methane amounting to 405 cc. The mixture with 1 part digested sludge and 1 part garbage had a somewhat lower gas yield, with a total gas pro-

duction of 605 cc. and a methane production of 305 cc. per gram of fresh dry volatile solids. The materials having 2 and 3 parts of garbage to 1 part of digested sludge were far from digested at the end of 48 days. The two mixtures, each containing different proportions of digested sludge, raw sludge and garbage, gave total gas yields only slightly less than the gas production from the control, which consisted of raw and digested sludge only.

The chemical analyses and the heat values of the gases evolved are given in Table III. The mixture which contained raw sludge but no garbage

TABLE III

CHEMICAL ANALYSES AND HEAT VALUE OF GAS PRODUCED FROM DIGESTING GARBAGE AND SLUDGE

Proportions of Materials Mixed[a]							
Digested Sludge, Parts	Raw Sludge, Parts	Garbage, Parts	CH_4, %	H_2, %	CO_2, %	N_2, %	Heat Value, B. t. u. per Cu. Ft.
1	2	0	62.6	2.5	24.4	10.5	676
1	1	1	57.9	3.9	28.9	9.3	630
1	½	½	55.5	4.1	26.9	13.5	605
1	0	1	50.7	4.1	32.4	12.8	554
1	0	2	48.5	5.6	30.9	15.0	536
1	0	3	45.7	4.4	35.2	14.7	502

[a] The proportions were based on the weight of dry volatile solids present.

evolved more methane than the mixtures containing garbage. On the other hand, the hydrogen production was 2.5 per cent from the mixture with no garbage and 4.1 per cent from the 1 to 1 mixture of garbage and digested sludge. The heat value of the gas from the former was 676 B. t. u. per cu. ft. and that from the latter 554 B. t. u. per cu. ft.

As is apparent from Figures 1 and 2, all of the mixtures, except those containing 2 and 3 parts of garbage, were digested at the end of about 30 to 35 days. In no case were the volatile solids in the digested materials at the end of the experiment higher than 52.6 per cent, with pH values varying from 7.2 to 7.4. The digested solids had entirely lost their disagreeable odor; they were dark brown in color, and their appearance indicated that they could be readily dewatered on sand filters.

Optimum pH Value for Garbage Digestion

The preliminary experiments were conducted to find out in a general way the possibilities of the anaerobic digestion of garbage when seeded with ripe sewage sludge. During this preliminary work the pH value of the materials was kept at 7.0 to 7.2. This pH was adopted because the sewage sludge at Baltimore[2] digests best at about this value. In order to

obtain more definite information about this question a series of observations were made with the pH values of the materials kept at 6.4, 6.8, 7.2, 7.6, 8.0 and 8.4. The mixtures which were studied contained, on the dry volatile solids basis (see Table IV), 2 parts (161.8 grams) of digested

TABLE IV

CHARACTERISTICS AND QUANTITIES OF GARBAGE, UNDIGESTED AND DIGESTED SLUDGE USED

(Materials Used in Determining Optimum pH Value for Garbage Digestion)

				Solids				
					Volatile		Ether-Soluble Matter	
Material	Weight, Grams	Moisture, %	pH	Total Gm.	Weight, Gm.	%	Weight, Gm.	% Dry Solids, Basis
Digested Sludge	3289.4	90.3	7.5	319.1	161.8	50.7	25.2	7.9
Undigested Sludge	782.9	86.4	4.8	106.5	80.8	75.9	42.6	40.0
Garbage	463.6	80.2	4.8	91.8	80.7	87.9	32.6	35.5

sludge, 1 part (80.8 grams) of undigested sludge and 1 part (80.7 grams) of garbage. One of the mixtures, which was used as a control, contained 2 parts of raw and 1 part of digested sludge. The pH value of this material was adjusted to 6.9 with lime at the beginning of the experiment. After that time no further lime additions were made. A final mixture contained only garbage, with no raw or digested sludge. The pH value of this material was kept at 7.0 with lime. The pH values of the mixtures of garbage and sludge were controlled by the additions of lime or hydrochloric acid. During the process of digestion the general tendency was for the mate-

TABLE V

CHEMICAL ANALYSES AND HEAT VALUE OF GAS PRODUCED FROM DIGESTING GARBAGE AND SLUDGE

(Materials Used in Determining Optimum pH Value for Garbage Digestion)

pH Value of Material	CH_4, %	H_2, %	CO_2, %	N_2, %	Heat Value, B. t. u. per Cu. Ft.
Control, pH unadjusted[a]	67.4	0	26.3	6.3	718
6.4	34.2	4.8	49.8	11.2	381
6.8	52.8	4.7	36.7	5.8	578
7.2	60.5	4.0	30.8	4.7	658
7.6	67.2	6.1	18.6	8.1	737
8.0	36.4	5.7	11.6	46.3	408
8.4	31.3	5.7	13.4	49.6	353

[a] Control contained a mixture of 1 part digested sludge and 2 parts raw sludge. All other mixtures contained 2 parts digested sludge, 1 part raw sludge and 1 part garbage. All proportions are on a dry volatile solids basis.

rials to become alkaline. As in the preliminary studies 10 lb. of wet material were used in each case, with all work in duplicate.

The progress and completion of digestion were determined by the quantity

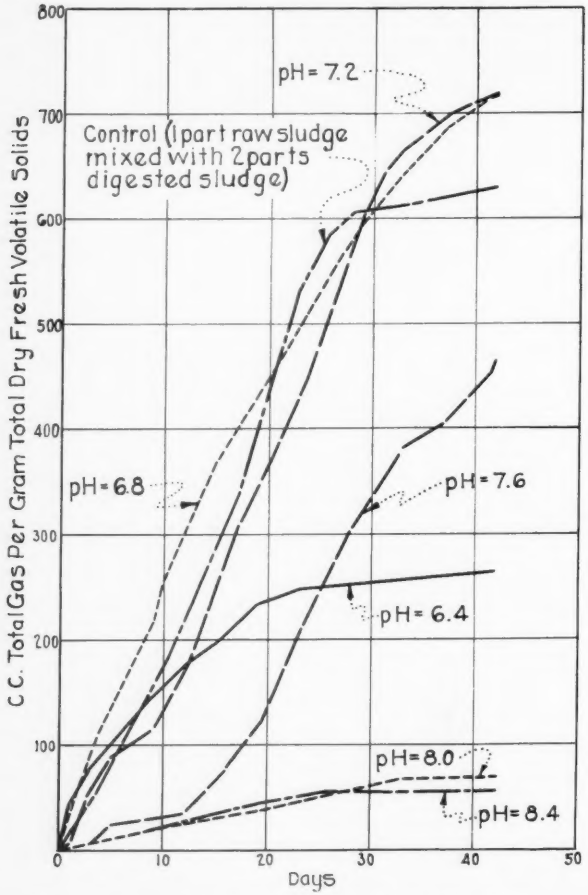

FIG. 3.—Relation of Various pH Values to Total Gas Production from the Digestion of Garbage with Sewage Sludge. The Mixtures, Consisting of 1 Part Raw Sludge, 2 Parts Digested Sludge and 1 Part Garbage, Were Incubated at 28° C.

of total gas and methane produced. These results are shown in Figures 3 and 4. The materials kept at pH values of 6.8 and 7.2 produced the most total gas, the amount being about 715 cc. per gram of dry fresh vola-

tile solids. The mixtures at pH values of 6.4 and 7.6 were only about half digested at the end of 42 days, when the experiment was discontinued. For the first 10 or 12 days the material held at a pH value of 6.4 digested quite rapidly, but after that time digestion was very slow. There was very little digestion of the solids kept at pH values of 8.0 and 8.4. More methane was produced by the mixture maintained at a pH value of 7.2 than from any of the other materials. There was no gas formation from the garbage to which no raw or digested sludge was added. Table V

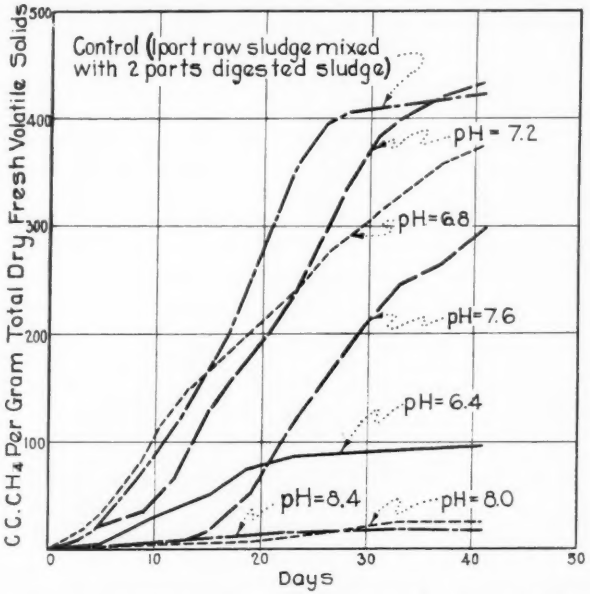

FIG. 4.—Relation of Various pH Values to Methane Production from the Digestion of Garbage with Sewage Sludge. The Mixtures, Consisting of 1 Part Raw Sludge, 2 Parts Digested Sludge and 1 Part Garbage, Were Incubated at 28° C.

gives the chemical analyses of the gases given off by the various sludges. As in the preliminary studies, it is apparent that garbage produces less methane and more carbon dioxide than sewage sludge. On the other hand, garbage evolves a larger quantity of hydrogen.

The results of the investigations have been sufficiently promising to warrant their continuance both in the laboratory and on a plant scale. The whole process of the digestion of garbage with sludge is one that has numerous possibilities. If continued observations both in the laboratory and on a larger scale should indicate that garbage can be economically

and satisfactorily digested with sewage sludge, it is possible that one more method of garbage disposal has been made available, with perhaps an extensive applicability. Even though the process is not adopted as a permanent method of treatment, it offers a means of garbage disposal for short periods of time, especially during the summer months, when the garbage plant is frequently overloaded and when the sewage works usually operates most efficiently due to warmer temperatures.

Several ways of disposing of garbage with sewage or sewage sludge offer themselves. The simplest, from the standpoint of sewage works operation, would be to haul the garbage to the sewage works, grind it up and then mix it with the raw sewage solids being added to the digested sludge. The experiments which have been conducted so far seem to indicate that this is a practicable method of disposal. It is, of course, obvious that more extensive facilities for handling the increased quantity of solids would have to be provided, such as additional digestion tanks, sludge drying equipment and means of final sludge disposal.

A second method of garbage treatment with sewage would be to provide one or more grinding stations in several parts of the city adjacent to the larger trunk and intercepting sewers, in which there would be sufficient velocity of flow to transport the finely ground material to the sewage treatment plant. This method would have one advantage over the first plan in that the cost of hauling the garbage would be much less than where the material would have to be conveyed to the sewage works. Several grinding stations could be erected so that the length of haul to each would not be great. Nothing is known as to what extent the ground garbage would increase the soluble material in the sewage, which would not be removed by sedimentation. Definite information would have to be obtained regarding this question to be sure of the feasibility of this method of garbage disposal.

A third scheme would be for each dwelling, restaurant and hotel to have its own grinding machine, preferably electrically operated, the discharge from which would connect with the house drain leading to the sanitary sewer. Each householder would then grind up his own garbage. If such a plan were adopted, the collection of garbage would be practically eliminated except where properties were not connected to the sewerage system or where it would be impossible for some other reason to install grinding equipment. At least one nationally known electric manufacturing company has been working on the development of such a grinder for domestic use for a number of years.

Considerable information is available as to the degree to which the solid content of sewage would be increased if the garbage were to be disposed of into the sewers. At Baltimore, for example, 79,508 tons of garbage[3] were collected in 1931. If it is assumed that this material contained

80 per cent water, there were 15,900 tons of dry solids present. In the same year there were about 16,400 tons of dry solids in the sludge removed from the preliminary settling tanks at the Baltimore sewage works.

Discussion

The results of the experiments made to date indicate the following conclusions, in so far as Baltimore conditions are concerned:

1. Garbage digests readily, either with or without raw sewage solids, when seeded with a sufficient volume of digested sludge.

2. At an incubation temperature of 28° C. the period for complete digestion is from 30 to 40 days.

3. The optimum pH value for digestion is from 6.8 to 7.2, which is the same as for Baltimore sewage sludge.

4. The digested material is free from offensive odor, and is in such a condition that it can be dried on sand beds.

5. The total quantity of gas production varies from 600 to 700 cc. per gram of dry fresh volatile solids, and the methane production varies from 300 to 400 cc. From 4 to 5 per cent of the gas evolved is hydrogen. The gas usually contains from 30 to 35 per cent carbon dioxide, which amount is greater than is normally produced from Baltimore sludge. This high percentage is most likely due to the large carbohydrate content of the garbage.

The sewage works where these experiments were conducted are under the general supervision of B. L. Crozier, chief engineer of the department of Public Works, and G. E. Finck, sewerage engineer, with G. K. Armeling, superintendent. Acknowledgments are due to J. W. Bushman, who assisted in the laboratory work.

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[2] C. E. Keefer and H. Kratz, "Digesting Sewage Sludge at Its Optimum pH and Temperature," *Ibid.*, **102**, 103 (Jan. 17, 1929).

[3] Anon., "Contract-Operated Destructor Plant to Revert to City in Ten Years," *Ibid.*, **109**, 231 (Aug. 25, 1932).

A Carbon Study of Sludge Digestion-Gas from Water

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Some time ago, Buswell and Boruff[7] reported in THIS JOURNAL the volume and weight of gas that are recovered during the quantitative anaerobic digestion of the various constituents found in sewage. These data indicate that the weight of gas produced always exceeds the weight of organic matter digested. (For a few exceptions, see references 7, 8 and 21.)

In earlier experimental plant studies, Buswell and Pearson[9] had obtained 1.25 pounds of gas per pound of volatile matter digested, but they had no definite proof at that time that their sampling and analytical errors were sufficiently low to justify their conclusions. To check these data and to determine possible sampling and analytical errors, they set up a 28-liter laboratory digester. All additions made to and withdrawals from this tank were carefully sampled and analyzed. The first attempt was somewhat of a failure as the tank contents became sour,[10] but the second time normal digestion was established. In summary the unpublished data show satisfactory balances, with a gas production, when corrected for dissolved CO_2 of 7.7 cu. ft. per pound of solids added, or 19.6 cu. ft. per pound of volatile matter digested, which amounts to 1.32 pounds of gas per pound of volatile matter digested. These data were obtained at an average feeding rate of 0.6 gram of total solids per day per liter of tank capacity (0.037 pound per cu. ft. per day).

The above data furnish additional proof that water enters the digestion reaction—the weight of the resulting gas being heavier than the solids removed by the amount of combining water. For further discussion of the mechanism of these reactions, the reader should consult references 7, 8 and 21.

Most of the gas data from large scale treatment plants, when calculated on a poundage basis, show the production of about a pound, or slightly less, of gas per pound of volatile matter digested. The writers feel that the reason for this is due to sampling and analytical errors in determining volume and solids content of the raw and digested liquors, as well as small errors in collecting, measuring and analyzing the gases produced. The difficulty of measuring and collecting representative samples from the large volumes of raw sludge added to, and the overflow and sludge liquors drawn from large disgesters is still not recognized by some investigators. The errors involved in these measurements, plus the large amount of CO_2 gas lost to the air when liquors are withdrawn from the digesters, account for the fact that most of the treatment plants report only one pound, or slightly less, of gas per pound of volatile matter digested. Examination

of treatment plant data furnished by Sperry, Larson, Rumsey[7], and more recently, Kraus[20] (see Table I), however, shows yields of gas the weight of which exceeds the weight of volatile matter digested (111 to 126 per cent).

Errors due to loss of ammonium acetate and ammonium carbonate during the total solids determination are significant[3] and are greater in the digested liquors (overflow and sludge) than in the raw solids, in which the ammonia nitrogen content is much lower; hence, data tend to indicate a greater loss of volatile matter through digestion than actually occurs. This error tends to lower the weight of gas collected per pound of volatile matter rather than to increase it.

Rudolfs,[1] in three laboratory experiments, recovered gas which weighed 91, 101 and 103 per cent, respectively, of the weight of the volatile matter digested. He reports the latter two values to be due to analytical errors, particularly the determination of volatile matter. The weight of a liter of CO_2 at 20° C. and 760 mm. pressure should have been computed at 1.84 grams ($1.977 \times 273/293$) instead of 1.79 grams. Using the correct value increases the yields to 93, 105 and 105 per cent, respectively.

A carbon balance study of sludge digestion, using a digester of sufficient size that the data would be significant, and yet small enough that the sampling errors would not be great, such a study to include carbon determinations on all substances added to and withdrawn from the digester, accompanied by accurate total and volatile solids determinations and gas data, should definitely settle the question as to whether or not the digestion of sewage solids leads to the production of a greater weight of gas than the weight of volatile matter lost through fermentation. To this end, the following studies were made.

Wet Combustion Method for Total Carbon

One of the first things found necessary in this study was to develop a wet combustion method capable of handling sludge. There are many wet combustion methods for determining carbon cited in the literature[13–18] but none was found suitable for samples of raw or digested sludge in which the carbon content may be as much as 40,000 p. p. m. In order to overcome sampling errors, it was thought advisable to use 20 cc. or more of sludge for analysis. This required greater CO_2 absorption capacity than given by any of the methods reviewed.

The apparatus developed and used is illustrated in Figure 1. The samples drawn were always immediately made strongly alkaline with solid NaOH in order to hold all dissolved CO_2. These samples (20 to 50 cc.) were then slowly added to the warm oxidizing solution in the digester. The oxidizing solution was composed of 200 cc. of conc. H_2SO_4, 50 cc. of conc. H_3PO_4, 35 cc. of saturated H_2CrO_4 and 1 cc. of $CuSO_4$ solution (10 per cent). It was noted that a much more uniform flow of CO_2 could be

obtained by adding the sample to the oxidizing solution rather than *vice versa*. The CO_2 evolved and a stream of CO_2-free air were drawn by suction through a purifying train composed of one tube containing warm H_2CrO_4, to oxidize any small amount of CO that might be escaping, a second tube containing KI and a small amount of H_2SO_4 to remove Cl_2, a third tube containing Ag_2SO_4 in conc. H_2SO_4 to remove HCl and any oxides of nitrogen or sulphur, then into a small bottle which acted as a spray trap, from which the CO_2 was led into the gas scrubber containing 200 cc. of normal NaOH. The CO_2-free air was continuously drawn through the apparatus at the rate of 60 to 80 small bubbles per minute. After all of the sludge had been introduced, the oxidizing solution was heated to gentle boiling and the aspiration of CO_2-free air continued for two to three hours. As a safeguard against loss of CO_2 through the absorber there were added

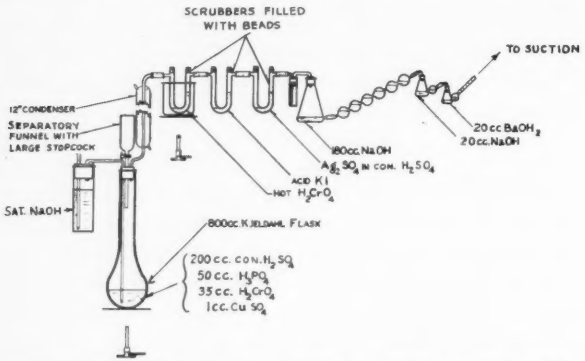

FIG. 1.—Wet Combustion Apparatus for Determination of Total Carbon.

at the exit end of the main absorber two small bulbs containing NaOH and $Ba(OH)_2$, respectively. The $Ba(OH)_2$ served as an indicator as to the efficiency of the absorption, for if CO_2 was passing the main absorber the $Ba(OH)_2$ would become cloudy. Such being the case, the rate of addition of the sludge was decreased. The NaOH and $Ba(OH)_2$ used in the small absorbers were always titrated and the amount collected in them, if any, added to that collected in the main absorber.

The carbonate formed in the NaOH absorber was precipitated by adding 50 cc. of saturated neutral $BaCl_2$. This mixture was heated almost to boiling and titrated slowly, while hot, with 0.5 *N* HCl, using phenolphthalein as the indicator. Thymolphthalein was tried as an indicator but the endpoint was hard to see in the $BaCO_3$ suspension. The NaOH, to which was added neutral $BaCl_2$, was standardized against the 0.5 *N* HCl, which was, in turn, standardized against C. P. Na_2CO_3.

Overflow liquors were analyzed by the same procedure as used for sludges. Less NaOH was necessary to absorb the CO_2. The large amount of conc. H_2SO_4 used in the oxidizer, namely, 200 cc., was necessary to overcome the effect of the water in the sludge.[15] The H_3PO_4 aided in holding the SO_3 in the hot solution.[13]

On weighed samples of pure dextrose, potassium acid phthalate and acetanilide, 98.6 to 99.9 per cent carbon recoveries were obtained. (See Table I.)

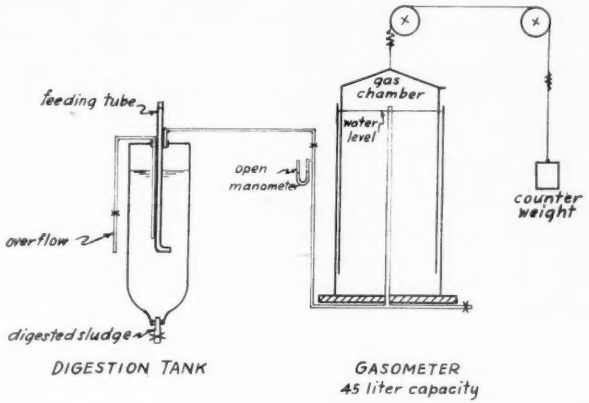

FIG. 2.—Experimental digester.

TABLE I

QUANTITATIVE CHECK ON WET COMBUSTION METHOD FOR TOTAL CARBON

Material Added	Carbon Added, Gram	Carbon Recovered, Gram	Per Cent Recovery
Dextrose	0.6293	0.6234	99.06
Potassium Acid Phthalate	0.8558[a]	0.8441	98.63
Potassium Acid Phthalate	0.8500[a]	0.8401	98.83
Potassium Acid Phthalate	0.8057	0.8045	99.9
Potassium Acid Phthalate	0.9885	0.9787	99.0
Acetanilide	0.0815	0.0811	99.57

[a] 0.5 Gm. NH_4Cl also added.

Sludge Digestion—Experimental

In this investigation, two 10-liter glass bottles were used as anaerobic digestion tanks. They were equipped as shown in Figure 2. The tests were originally started by adding to the tanks digested sludge and overflow liquor from a sludge digestion tank. Fresh raw solids, collected at the Water Survey experimental treatment plant (Urbana-Champaign

sewage), were fed, a liter at a time, three times a week and overflow liquor or digested sludge withdrawn, two liters at a time, just prior to alternate feedings. The rate of feeding at the start was regulated through volatile acid control so that the volatile organic acid content at no time was over 800 p. p. m., calculated as acetic. After normal fermentation was estab-

TABLE II

SLUDGE DIGESTION; GENERAL DATA

Continuous Feeding, 25–30° C.

	Tank 1	Tank 2
Volume of Digesters, Liters	9.5	9.5
Days Operated	120	120
Total Solids Fed:		
Weight, Gm.	2242.6	2242.6
Volume, Liters	46	46
Fed, Gm. per Day per Liter Tank Capacity	1.97	1.97
Gas Recovered:		
Total Volume:		
Actual, Liters, S. T. P.	928.2	848.4
Corrected for Dissolved Gas,[b] Liters	970.3	890.5
Total Weight, $CO_2 + CH_4$:		
Actual, Gm.	940.3	843.9
Corrected for Dissolved Gas, Gm.	1021.3	921.8
Analysis		
As Recovered, Per Cent by Volume		
CO_2	25.9	25.0
CH_4	70.0	70.0
N_2	4.1	5.0
Corrected for Dissolved Gas,[b] Per Cent by Volume		
CO_2	29.0	28.4
CH_4	67.0	66.7
N_2	4.0	4.9
Gas Produced per Gm. Volatile Matter Fed:		
Actual, Gm. per Gm.	0.632	0.567
	0.625[a]	0.561[a]
Corrected,[b] Gm. per Gm.	0.686	0.619
Actual, Liters per Gm.	0.624	0.570
	0.617[a]	0.564[a]
Gas Produced per Gm. Volatile Matter Digested:		
Actual, Gm. per Gm.	1.33	1.13
	1.35[a]	1.15[a]
Corrected,[b] Gm. per Gm.	1.44	1.23
Actual, Liters per Gm.	1.31	1.14
	1.39[a]	1.16[a]

[a] Corrected for probable loss of NH_4HCO_3 during total solids-volatile matter determination.

[b] Corrected for gain in dissolved CO_2 and CH_4 in liquors withdrawn and gas liberated at end of experiment when tanks were treated with H_2SO_4.

lished the acid content remained about 200 p. p. m. and the pH between 7.1 and 7.2. The temperature varied between 25° and 30° C. (77° to 86° F.).

Gas was collected, measured, corrected to standard conditions and analyzed in a modified Orsat apparatus. All liquors fed and withdrawn were analyzed for total solids, volatile matter, ammonia and total nitrogen and total carbon. All analyses were made according to Standard Methods of Water Analysis.[12] Carbon analyses were made by the method already described in this article. A 100-cc. sample of all liquors added and withdrawn was dried and composited for cellulose, lignin and other special tests. (See Table VI.) After a preliminary run of 45 days, the digesters were emptied, sampled and a trial balance made to determine the accuracy of the sampling and analytical procedures. As this trial balance gave satisfactory results, the tank contents were returned to the digesters and the final 120-day digestion experiment reported in this article was started. The air in the small gas space at the top of the digester was swept out with sludge digester gas.

At the end of this run both tanks were dosed and mixed with dilute H_2SO_4 (to neutrality) to drive off the dissolved and the combined CO_2. The liquor was then withdrawn without loss of CO_2. The tanks were washed clean with CO_2-free distilled water and the washings added to the liquor withdrawn.

Feeding Rate.—During the 120-day run, raw sludge was fed at an average rate of 1.97 grams total solids, containing 1.13 grams of carbon, per liter of tank capacity per day. (See Table II.) This is equivalent to 0.123 pound of total solids per cu. ft. of tank capacity per day and is of the general order of magnitude of the loading of digesters in most sewage treatment plants. In this respect the data are more comparable to plant operation data than those collected by Pearson and Buswell, in which solids were fed at an average rate of only 0.04 pound per cu. ft. of tank capacity per day. Rudolfs' carbon studies were made on batch digestions.[1]

Gas Production.—As noted in Table II, gas was produced in the two digesters at the average rate of 0.814 and 0.745 liter per day per liter of tank capacity, or 0.414 and 0.378 liter, respectively, per gram of total solids fed (6.6 and 6.1 cu. ft. per pound of total solids fed). This is equivalent to 0.632 and 0.567 liter, respectively, per gram of volatile matter fed (10.1 and 9.1 cu. ft. per pound of volatile matter) or 1.31 and 1.14 liters of gas, respectively, per gram of volatile matter digested (21.0 and 18.2 cu. ft. per pound of volatile matter digested). These gas production data are comparable to the mass of gas production data noted in the literature.[2,11]

Carbon Balance.—In the first tank, the weight of the carbon in the inoculum, plus that in the raw sludges fed, amounted to 1210.6 grams (Table III). The carbon left in the tank at the end of the run, plus that

TABLE III

TOTAL CARBON BALANCE

	Tank 1, Gm.	Tank 2, Gm.
Added:		
Inoculum	190	175
Raw Sludge	1020.6	1020.6
Total	1210.6	1195.6
Withdrawn:		
Overflow Liquors	47.7	46.3
Digested Sludge	320.4	306.3
Final Mixture	331.0	310.0
Total	699.1	662.6
Removed through Digestion	511.5	533.0
Recovered in Gas	478.6	430.3[a]
Unaccounted for	32.9	102.7
Per Cent Lost	2.7	8.6

[a] Thought to be low due to loss of gas.

found in all the overflow liquors, sludges and gases withdrawn, amounted to 1177.7 grams. This means that a negative error of 2.7 per cent was noted in the carbon balance. This error is within sampling and analytical limits. An 8.6 per cent loss was recorded for the second tank. All the data indicate that some gas must have been lost from the second digester. If the gas data are corrected for the probable gas analysis error mentioned in the next paragraph, the increase in weight due to the CH_4 might be as much as 20.4 and 22.6 grams of carbon, respectively. This would reduce the carbon balance error in the two tanks to 1.03 and 6.7 per cent, respectively.

Nitrogen Balance.—The weight of the nitrogen in the inoculum plus that in the raw sludges added to the first and second tank amounted to 91.2 and 89.7 grams, respectively, while the nitrogen left at the end of the run plus that found in the overflow liquors and sludges withdrawn

TABLE IV

TOTAL NITROGEN BALANCE

	Tank 1, Gms.	Tank 2, Gms.
Added:		
Inoculum Mixture	23.0	21.5
Raw Sludge	68.2	68.2
Total	91.2	89.7
Withdrawn:		
Overflow Liquors	21.6	21.8
Digested Sludge	33.0	30.8
Final Mixture	40.0	35.0
Total	94.6	87.6
Change, Gain or Loss	+3.4	−2.1
Per Cent Change	+3.7	−2.3

TABLE V

TOTAL SOLIDS AND VOLATILE MATTER DIGESTED

	Tank I				Tank II				
	Total Solids		Volatile Matter		Total Solids		Volatile Matter		Volume
	As Determined, Gms.	Corrected, Gms.[d]	As Determined, Gms.	Corrected, Gms.[d]	As Determined, Gms.	Corrected, Gms.[d]	As Determined Gms.	Corrected, Gms.[d]	Liters
Added:									
Inoculum	576.7	605.9	303.9	333.1	522.4	552.8	255.2	285.6	10.0
Raw Sludge	2242.6	2258.3	1488.5	1504.2	2242.6	2258.3	1488.5	1504.2	46.0
Total	2819.3	2864.2	1792.4	1837.3	2765.0	2811.1	1743.7	1789.8	
Withdrawn:									
Overflow	88.9	163.5	51.8	126.4	94.6	168.0	53.8	127.2	35.5
Digested Sludge	996.2	1028.0	506.3	538.1	972.5	1005.1	468.8	501.4	10.0
Final Mixture[e]	1025.0 (1017.5)[b]	1017.5	526.0	498.8[c]	927.5 (920.0)[b]	920.0	474.5	448.1[c]	[f]
Total	2102.6	2209.0	1084.1	1163.3	1987.1	2093.1	997.1	1076.7	
Digested	716.7	655.2	708.3	695.7[a]	777.9	718.0	746.6	734.2[a]	
Per Cent Digested	25.4	22.8	39.6	37.8	28.1	25.6	42.6	41.0	

[a] Corrected for gain in weight (1.30 times) of amino acid group during liquefaction to NH_4HCO_3.
[b] Corrected for conversion of carbonate to sulphate.
[c] Corrected for loss of ammonium sulphate during ignition.
[d] Corrected for probable loss of NH_4HCO_3 during total solids-volatile matter determination.
[e] Treated with H_2SO_4 to convert NH_4HCO_3 and other bicarbonates to sulphates and release CO_2.
[f] 10.2 liters (Tank 1); 9.9 liters (Tank 2).

mounted to 94.6 and 87.6 grams, respectively. (See Table IV.) There was, therefore, a positive error of 3.7 per cent noted in the nitrogen balance data for the first tank and a negative error of 2.3 per cent in the second tank. These balances are also well within the limits of sampling and analytical errors. Only about 2 grams of the total 47 and 53 grams of nitrogen found in the gas can be accounted for as nitrogen gas dissolved in the sludges added. The rest is undoubtedly due to additive error produced by incomplete combustion in the 23 gas analyses made on the gas produced. If all of this apparent N_2 were actually CH_4 which was not burned in the combustion pipette, this error would account for 20.4 and 22.8 grams of the carbon unaccounted for in the carbon balance of the two digesters. The close balance noted for total nitrogen added and recovered in the liquors further substantiates the previous work of Buswell and Strickhouser that there is little or no free nitrogen (N_2) produced during sludge digestion.

Ash Balance.—The ash balance shows an 0.8 per cent loss in the first and 3.1 per cent loss in the second tank. There were 1026.9 grams of ash added and 1018.5 grams recovered in the first digester while 1021.3 grams were added and 990.0 grams recovered from the second tank. These data are corrected for the H_2SO_4 added.

Solids Digested.—As noted in Table V, 25.4 per cent of the 2819.3 grams of total solids added and 39.6 per cent of the total volatile matter added to the first tank were digested. Likewise, 28.1 per cent of the 2765.0 grams of total solids, or 42.6 per cent of the volatile matter added to the second tank, was digested. These percentage figures are somewhat reduced if the solids data are all corrected for the probable loss of all of the ammonia nitrogen as NH_4HCO_3 during the process of drying of total solids sample. * It is noted that this correction amounts to less

* Data in "Corrected" columns (Table V) have been corrected for probable loss of all of the ammonia during the total solids determination as NH_4HCO_3. Since H_2SO_4 was added to the "final mixture" liquors to convert NH_4HCO_3 to $(NH_4)_2SO_4$ prior to opening the tanks, and as the latter is non-volatile at 103° C., correction has been made in the total solids data only for the change of carbonate present to sulphate. The figure for volatile matter digested cannot be obtained by merely subtracting the corrected total solids withdrawn from those added, due to the fact that the gain in NH_4HCO_3 in the final liquor represents 130 per cent of the weight of the amino and carboxyl groups originally present in the protein decomposed. The following reaction will serve to illustrate this particular step in the breakdown:

$$\begin{matrix} & & & & & & & & \\ & & & & & & & & \\ \mathrm{RCH} & \vdots & \mathrm{NH_2COOH} & \vdots & + & 2\mathrm{H_2O} & = & \mathrm{RCH_2OH} & + & \mathrm{NH_4HCO_3} \\ & \vdots & 61 & \vdots & & & & & & 79 \\ & & & & & & & & & \end{matrix}$$

The additional NH_4HCO_3 found in the digested sludges and overflow liquors in Tank I, over that present in the inoculum and raw sludges, was noted to be 94.0 grams. This represents the digestion of 94.0/1.30, or 72.3 grams of original amino and carboxyl groups. The "volatile matter digested" data must, therefore, be corrected for the gain

than 1 per cent for the raw sludge but runs from 2.2 to 3.4 per cent for digested sludges. The error in determining the total solids content of overflow liquors, which contain a high concentration of NH_4HCO_3, as noted in Table V, may be as much as 84 per cent. (Total solids: As determined, 88.9 grams; corrected for loss of NH_4HCO_3, 163.5 grams.)

Table VI gives an idea of the percentage composition of the solids added

TABLE VI

PER CENT COMPOSITION OF SOLIDS ADDED TO AND WITHDRAWN FROM TANKS[d]

	Inoculum and Raw Sludge	Digested Sludge	Overflow Liquor	Final Tank Contents
1. Hot Water Soluble[a]	10.66	6.63	22.26	8.51
2. Petroleum Ether Soluble	20.8	6.9	1.4	10.5
3. Ethyl Alcohol-Benzene Sol.	7.4	1.35	3.34	1.9
4. Hemicelluloses[c]	1.21	0.73	0.68	1.75
5. Cellulose[c]	3.89	2.3	2.34	4.96
6. Lignin and Humus[c]	8.3	12.05	3.94	10.9
7. Protein[b]	16.5	10.9	17.9	15.8
8. Ash	36.6	50.5	42.4	47.4
9. Total Accounted For	105.36	91.36	94.36	101.72

[a] Corrected for ash.

[b] (Total N less ammonia N) × 6.25 = protein.

[c] Analysis according to Waksman and Stevens, *Ind. Eng. Chem., Anal. Ed.*, **2**, 167 (1930).

[d] These analyses made on dried mixture of composites from both tanks; hence, some data vary slightly from individual tank data.

and removed. Analyses 1 to 6, inclusive, were made in succession on the same dried composite sample referred to earlier in this article. Table VII indicates the relative amounts and percentages of the various con-

TABLE VII

GRAMS OF VARIOUS SUBSTANCES ADDED TO AND WITHDRAWN FROM DIGESTERS

	Inoculum and Raw Sludge	Digested Sludge	Overflow Liquor	Final Tank Contents	Digested Grams	Digested Per Cent
1. Hot Water Soluble	596.0	130.5	40.8	166.0	258.7	43.4
2. Petroleum Ether Soluble	1169.0	135.8	2.6	205.0	825.6	70.6
3. Alcohol-Benzene Sol.	413.5	26.6	6.1	37.1	343.7	83.1
4. Hemicelluloses	67.6	14.4	1.2	34.2	17.8	26.3
5. Cellulose	217.2	45.2	4.3	96.8	70.7	32.6
6. Lignin and Humus	464.0	237.0	7.2	212.8	7.0	1.5
7. Protein	922.0	214.5	32.9	308.4	366.2	39.7
8. Ash	2046.0	994.0	77.8	922.3	51.9	2.6
9. Total	5895.3	1798.0	172.9	1982.6	1941.8	33.0

in weight of 21.7 grams (94.0 − 72.3) before the loss of organic matter through digestion can be calculated. The correct "digested" figure for Tank I would, therefore, be 1837.3 − 1163.3 + 21.7, or 695.7 grams. The volatile matter digested (corrected) for Tank II was calculated in the same manner.

stituents that were digested. The petroleum ether and alcohol-benzene-soluble fractions are composed mainly of fats and soaps with smaller amounts of waxes and resins. These constituents were removed to a greater extent than any other. They account for 61 per cent of the total loss in organic matter. Thirty-three per cent of the cellulose and 40 per cent of the protein added were removed through digestion. These constituents account for only 4 per cent and 19 per cent, respectively, of the total organic matter digested. These data again indicate that the greater portion of the gas formed during sludge digestion is due to the decomposition of the fats and soaps.[8,9] This is especially true of sewage from the hard water regions and certain other districts, where much fat, grease, or soap enters the sewage. Fatty acids and soaps, due to their low oxygen content, furnish large volumes and weights of gas per unit weight of material digested.[7,8]

The following reaction for the fermentation of glycerol stearate may serve to illustrate:

$$4(C_{17}H_{35}COO)C_3H_5 + 106H_2O = 65CO_2 + 163CH_4$$

Each gram of this representative fat upon digestion furnishes 1433 cc. of gas which weigh 1.54 grams and contain 72 per cent methane. The other constituents found in sludge furnish lower volumes and less weight of gas per unit weight digested.[7]

Summary

As stated in the introduction, the main object of this investigation has been to operate two moderately large laboratory digesters at a normal sludge digestion rate to determine how accurately a carbon balance could be obtained, and to obtain data on gas production. A satisfactory carbon balance has been obtained, especially on the first digester. This indicates that the sludge and liquor samples have been representative and that no excessive volumes of gas have been reported. The ash balances obtained in these studies also indicate that the solids data are accurate. Given this assurance, namely, that the data are accurate and representative, we are now prepared to present the gas data in terms of yield per unit weight of volatile matter digested. As noted in Table II, each gram of volatile matter digested in Tank No. I produced 1.33 grams of gas. This value is increased to 1.44 grams if the gas data are corrected for the CO_2 held in solution by the liquors or to 1.35 if the solids data are corrected for the probable loss of ammonium salts, as NH_4HCO_3, during drying. (The latter includes only part of the dissolved CO_2 correction.) Likewise, each gram of volatile matter digested in the second tank produced 1.13 grams of gas. This value, when corrected for increase in dissolved CO_2, becomes 1.23 which becomes 1.15 if the solids are corrected for the probable loss of NH_4HCO_3. All conceivable corrections have been

made in the total solids and volatile matter data, yet, as noted, these have little effect on the final data.

The production of 1.44 grams of gas (corrected for dissolved CO_2) per gram of organic matter decomposed is to be expected from previous investigations.[7,8] Fats and soaps account for 61 per cent of the total loss in organic matter in these digestions; those of higher molecular weight, which are the ones found in sewage, furnish 1.50 to 1.55 grams of gas per gram of material decomposed.

The above data, backed by the experimental plant data already reported by Buswell and Pearson, the academic studies made on the digestion of pure compounds, and the data from a few large-sized plants, should definitely establish the fact that the anaerobic digestion of sewage solids produces carbon dioxide and methane, the weight of which exceeds the weight of the volatile matter removed due to reaction with water. The average weight of gas *collectable* per pound of volatile matter digested is probably about 1.2 pounds. As stated in an earlier communication, differences in the chemical make-up of the solids digested would make some difference. The concentration of the raw solids fed and the digested sludge drawn would also affect this figure in that thinner raw sludges would mean the withdrawal of more overflow liquor or sludge with corresponding greater losses of dissolved CO_2.

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Stale Return Sludge as a Factor in the Activated-Sludge Process*

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In efforts to secure the greatest rate and degree of sewage purification by the activated-sludge process it is easy for the operator to overlook the important effect of the condition of the return sludge. Very often temporarily poor purification or inconsistent operation of the aerators are attributed to an unusual character of the raw sewage, which may place a temporarily high organic load on the plant or interfere with the normal functioning of the tank organisms due to the presence of some toxic substances. However, deterioration of the return sludge may play an equally important rôle in reducing the efficiency of purification through the aerators. The fundamental quality of the return sludge is dependent on the type of sewage treated and the environmental conditions in the aeration tanks. The quality of sludge may also be greatly modified by the method of handling between the time it leaves the aerators and is returned and mixed with the incoming sewage. One of the most important factors in modifying or changing the quality of the return sludge is the degree of concentration it receives in the final settling tank.

Some operators seem to prefer a highly concentrated return sludge with high solids content and low volume of return sludge. The other extreme is a thin return sludge with low solids content and a high volume of return sludge. Both methods may be said to have their advantages and disadvantages. In the case of a highly concentrated sludge more aeration capacity is preserved for contact with the incoming sewage than in the case of low sludge concentration and high volume. However, at the same time this advantage of more aeration capacity is offset to a certain extent by greater staleness and formation of toxic substances in the more highly concentrated return sludge.

The senior author has always felt that the greater disadvantage to satisfactory purification would come from the more highly concentrated return sludge. Consequently at activated-sludge plants under his supervision it has always been customary practice to maintain activated sludge in a very fresh condition by carrying a large volume of return sludge and low concentrations of solids, even though the aeration period was correspondingly reduced to a considerable extent. The large volume of sludge meant a return sludge of very low solids content.

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Investigation and Data

Recently studies were carried on at an activated-sludge plant, under the writers' supervision, with respect to the relative advantage of high or low concentration of the return sludge. These studies consisted of (1) the effect of concentration on fresh return sludge with respect to the increase in staleness of the sludge and (2) the decrease in efficiency the more highly concentrated, and incidentally staler, sludge would cause in the purification process.

In making these comparisons it was first necessary to select some test which would furnish at least some relative index as to whether the quality of the sludge varied with different concentrations. The most convenient

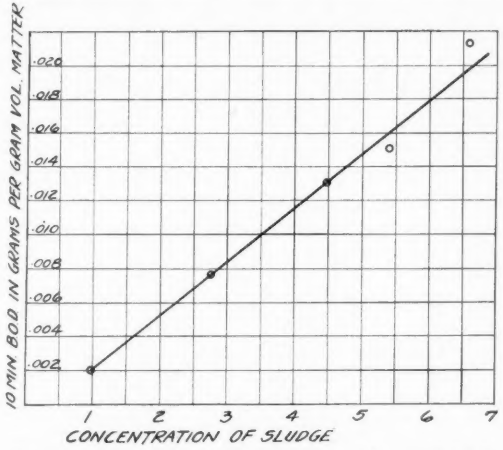

FIG. 1.—Effect of Increasing Concentration on Initial B. O. D. of Return Sludge.

test at the time of these investigations proved to be a 10-minute or hourly B. O. D. While it was realized this test was inadequate from the standpoint of measurement of specific quality of return sludge, it did give an overall index of relative value. It also represented the immediate demand on the oxygen supply when the return sludge entered the aerators.

The first part of the study, namely, determination of the degree of staleness of the return sludge by concentration in the absence of re-aeration facilities, was performed in such a manner as to simulate the effect of concentrating the fresh activated sludge, from the aerator, in the final settling tank sumps under a reduced oxygen supply and eventually under anaerobic conditions.

Fresh activated sludge from the outlet end of the aerators was placed in cylinders and allowed to stand and concentrate for a pre-determined

period. The increasing septicity was noted during this period by means of the 10-minute B. O. D. mentioned above. The results of this study are given in Figure 1, which shows the increasing staleness of the sludge through concentration, on the basis of grams B. O. D. per gram of volatile matter in the sludge. The concentration value in Figure 1 is the ratio of volume of sludge at the beginning of the test to the volume occupied by the sludge after consecutive intervals of time. The figure has been constructed from averaged results. These curves clearly demonstrate a rapid deterioration of the activated-sludge floc, even with comparatively low

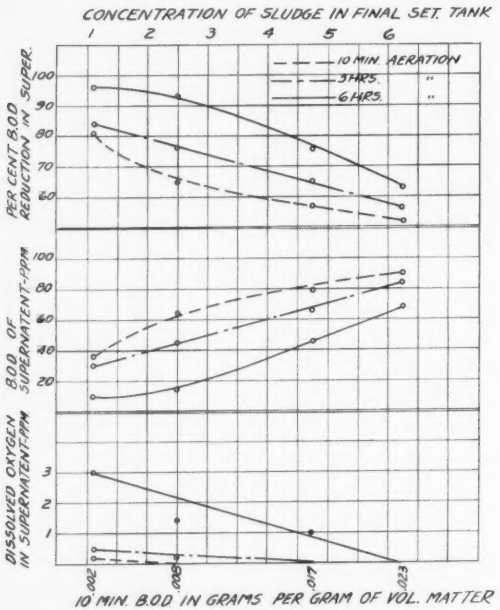

FIG. 2.—Effect of Increasing Concentration of Return Sludge on Purification through Plant.

concentrations. The B. O. D. increase per gram of volatile matter was roughly directly proportional to the concentration of the sludge. The time interval involved between concentrating the sludge from 1 to 5 times increased the 10-minute B. O. D. of the material over 650 per cent. Theoretically, therefore, high concentrations of return sludge should produce a heavy initial demand for oxygen in the aerators and the presence of toxic substances accompanying the septicity should result in decreased rate of purification.

To confirm this belief, the study was carried further to the aerators

to determine the practical effect of increasing staleness of return sludge on the purification process. This consisted of determining the relation between the progressive purification through the aerators and the 10-minute B. O. D. of the return sludge. The B. O. D. of the return sludge was varied by increasing or decreasing the concentration of the sludge in the final settling tanks. Figure 2 shows the relation found between the quality of the return sludge as measured by the 10-minute B. O. D. and the rate and degree of purification through the aerators. All figures shown in the curve were determined from the supernatant liquor of the activated-sludge mixture after a half hour settling. The same amounts of suspended solids were maintained in the aerators throughout the test period. The concentration in this figure is represented by the ratio of suspended solids in the return sludge to suspended solids in the aerator by weight.

The direct effect of the staler return sludges was noticeable throughout the entire length of the aerator. The B. O. D. reduction of the sewage liquor was affected in an approximately direct proportion to the staleness of the return sludge. Increasing the concentration of return sludge from 1 to 6 resulted in a decrease of about 33 per cent in the B. O. D. reduction through the aeration units. Intermediate values gave decreases in efficiency in a more or less direct proportion to the B. O. D. of the return sludge or concentration.

Dissolved oxygen was likewise decreased by the increased staleness of the return sludge. The staler return sludges affected most noticeably the D. O. content after 6 hours aeration.

Discussion

The investigations previously discussed were for purposes of control at this specific plant. For that reason the actual figures secured are probably of value only for this plant. However, they serve well to illustrate the value of maintaining a fresh and dilute return sludge, preferably by quick return from the final settling tank. In this case the purification process was greatly reduced throughout the entire length of the aerator by increased concentration of return sludge. If a straight-line purification curve is assumed, an additional aeration capacity of at least 30 per cent would be required to offset the deleterious effects of the stalest return sludge encountered in this study by 6 concentrations, which does not exceed that found under what are often considered normal conditions of operation.

The decreased efficiency may be due to one or both of two causes. The increased demand for oxygen of staler sludges may exceed the available oxygen supply, especially at the beginning of the aerators and consequently delay purification in the tank; or the presence of toxic substances formed

in the staler sludges may delay the activities of the organisms effective in purification. The latter is probably the greater factor. In either event the overall effect is to require additional aeration, either in the form of longer periods in the aeration tanks or re-aeration of the return sludge.

The results also illustrate that measurements of purification efficiencies through aerators must be tied up with more than the strength and character of incoming sewage. The character and quality of return sludge is probably of even greater importance to such efficiency measurements than is the incoming sewage. Varying qualities of return sludge may greatly becloud the effect of other factors in measuring the purification ability of aeration tanks.

Of all the routine plant tests carried on at the plant under discussion the tests for control of quality of return sludge have proved to be of equal if not greater value in developing and maintaining good purification results. The tests which have been used for this purpose are the 10-minute B. O. D. of the return sludge and the concentration of sludge in the final settling tanks. The 10-minute B. O. D. is admittedly a crude method of measurement of the quality of return sludge and as a matter of fact is not necessary after preliminary investigations are made for basic data. The important index seems to be the ratio of suspended solids in the return sludge to the suspended matter carried in the aerator, or in other words the concentration of the return sludge. The lower the sludge concentration the plant is able to carry the more efficiently the purification process will perform. At this plant the ratio between the suspended solids in the return sludge and those required in the aerator is maintained between 2.5 to 3.0 for satisfactory purification at all ranges of solids between 1200 and 3000 p. p. m.

Summary

The rate and degree of purification through an activated-sludge plant may be decidedly impaired by concentration of the return sludge in the final settling tank sumps. This concentration allows the sludge to grow stale at a rapid rate. Even a moderate deviation of the sludge from its original condition by virtue of short concentrations greatly reduces the rate of purification through the aerators. The affect of this stale return sludge is most important on plants with comparatively short detention periods.

Curves are given to show the reduced efficiencies of the process with varying degrees of staleness of the return sludge. This efficiency may be impaired by as much as 30 per cent under normal operating conditions of activated-sludge plants.

Some index for use in maintaining a good quality of return sludge is as vitally important to good activated-sludge plant operation as any of the other important indices used for plant control. At this plant the index

used is the ratio between the suspended solids in the return sludge and the suspended solids in the aerator, which represents the degree of concentration of the return sludge in the final settling tanks. The lower the ratio or concentration the more efficiently the purification process will perform. This has been verified by studies of the effect of ratios between 1 to 6 at this plant. A ratio of 2.5 to 3 has proved satisfactory for normal operating requirements at this plant.

The results also illustrate that in measurements of purification efficiencies through activated-sludge plants, the consideration of the condition of the return sludge is of as much if not more importance than the strength and character of the sewage treated.

Plant Operation

The Lima Sewage Treatment Plant

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Lima, Ohio, a city of 43,000 people, is located about 75 miles due south of Toledo, in the northwestern part of Ohio on the Ottawa River. The city with its present limits comprises an area of approximately 4500 acres. The topography is, for the most part, flat, sloping generally to the south and west.

History.—Troubles with the sewage system in Lima date back to 1900, at which time the State Board of Health ordered the old sewers relieved. In 1910 work was started on these sewers. In 1916 the State Department of Health ordered Lima to prepare plans for a complete sewerage system and sewage treatment plant to relieve the badly polluted Ottawa River. These plans were prepared and approved in 1921. The major portions of the relief sewers, interceptors, outfall sewers, pump stations, regulators and syphons were constructed between 1921 and 1928. In November, 1929, the voters authorized a bond issue to be used for the purpose of constructing a sewage treatment plant and improving the conditions in the Ottawa River, the construction of which had been held up because of controversies arising over the type of treatment to be used. In June, 1930, H. P. Jones & Company, Toledo, Ohio, were authorized to prepare plans and specifications for an activated-sludge type plant. Work was started in 1930 and completed in 1931.

Description of Plant.—Due to the topography of Lima, it is necessary that approximately $^2/_3$ of the total sewage flow be pumped twice before it is finally lifted into the 54 in. outfall sewer having a capacity of 28 m. g. d., which empties into the sewage treatment plant. The plant is located about 3 miles from the center of the city just south of the Chicago and Erie R. R. on the west bank of the Ottawa River (Figure 1). The site is completely surrounded by a dike to protect the plant from high water. The area inside the dike comprises 12.4 acres and the layout has been arranged so that all units may be duplicated and plant capacity doubled. In order to reach this site, a reinforced concrete bridge had to be constructed across the Ottawa River.

The treatment plant, which is of the activated-sludge type (Figure 1) with separate sludge digestion, consists of the following units:

Diversion Chamber
Bar Screen
Screenings Incinerator
Grit Removal Tank
Primary Settling Tanks
Sludge Pumping Station
Overflow Chamber
Aeration Tanks
Aeration Control Houses
Final Settling Tanks
Outfall Control Chamber
Main Building
Sludge Digestion Tanks
Digester Control House
Glass-Covered Sludge Drying Beds

The plant is designed to produce an effluent which can be emptied into the river during periods of low stream flow whithout causing any nuisance. The plant is designed for a population of 70,000 people and an estimated

FIG. 1.—General View of the Lima Plant and Bridge. Taken from the Railroad Bridge in the Northeast Corner of the Site.

average dry weather flow of 7 m. g. d. The screen, grit-removal tank and primary settling tanks are designed for a maximum flow of 14 m. g. d. and the aeration units and final settling tanks are designed for a maximum of 10 m. g. d. with 25 per cent returned sludge. Digestion capacity of 3.1 cubic feet per capita of design (70,000) population is provided in the separate sludge digestion tanks, and the sludge drying beds are proportioned for 0.5 square foot per capita.

Screen Building, Incinerator and Grit-Removal Tank.—Sewage flows from the diversion chamber into the screen building, and through a mechanically cleaned Dorr bar screen having $^3/_4$-inch clear openings. By means of two floats operated by the water level on the up-stream and down-stream sides of the screen, respectively, the cleaning mechanism

operates when the accumulation of screenings causes a predetermined loss of head through the screen.

Adjacent to the screen, inside the screen building, is a Dorr incinerator having a capacity of 2 cu. ft. of screenings per hour, and fired by combination gas and oil burners which permit the use of fuel oil or gas generated in the digestion tanks or a combination of the two fuels.

The arrangement for removing grit consists of a concrete tank 20 ft. square and 3 ft. deep, built adjacent to the screen building; and a raking channel located inside the screen building. As the screened sewage flows across the tank, the particles of grit settle to the bottom and are discharged into the raking channel by means of the scrapers and buckets of a Dorr

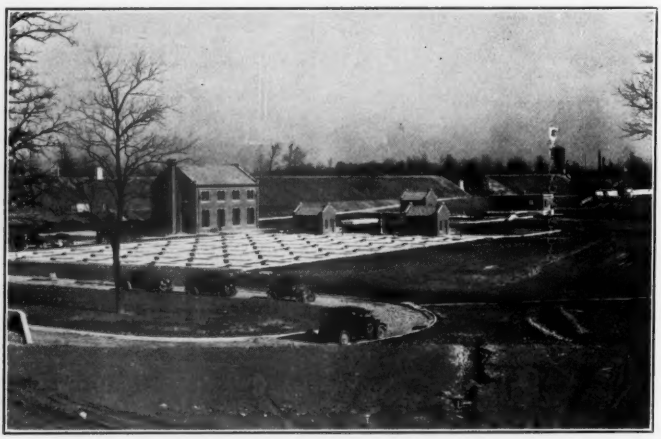

FIG. 2.—General View of the Lima, Ohio, Sewage Treatment Plant. Taken from the Digestion Tanks at the Southwest Corner of the Site.

rotating mechanism. The raking channel is provided with equipment which gradually rolls the grit particles up an inclined slope out of the sewage, washes the organic material back into the tank and discharges the grit into a storage hopper. The character of the grit removed is such that it can be used as fill material without creating any objectionable odors.

Primary Settling Tanks.—From the grit-removal tank the sewage flows through a 33-in. concrete conduit into two primary settling tanks equipped with Dorr sludge-collecting mechanisms, each tank being 55 ft. square and 11 ft. 6 in. deep at the edges. Allowing 18 in. freeboard, these tanks provide a detention period of $1\frac{1}{2}$ hours based upon 7 m. g. d. flow. The sewage flows from the bottom of the influent channel into each tank through fourteen 8 by 8-in. submerged ports, and from each tank through eight 12 by 12-in. submerged openings, with adjustable gates,

into the effluent channel. This arrangement was adopted to assist in maintaining as high a hydraulic gradient through the plant as possible, and the observed loss of head from the junction of the influent channels to the junction of the effluent channels amounted to only 0.2 ft. at 6 m. g. d. flow.

The collecting mechanisms are provided with electrical controls and alarms which function to sound an alarm and shut down the units in event of stalling due to an excessive accumulation of sludge or the formation of ice on the rails.

Sludge Pumping Station.—In the sludge pumping station are located two Dorr duplex, variable-stroke, plunger pumps for discharging the primary tank sludge to the digestion tanks. The suction piping is arranged so that either pump can draw from either tank, and so that either tank can be emptied without the use of the pumps.

FIG. 3.—Aeration Tanks and Control Houses. Lima, Ohio, Sewage Treatment Plant.

Overflow Chamber.—In the effluent line from the primary tanks is an overflow chamber having a long overflow weir, a 30-in. valved settled sewage connection leading to the aeration units, and a direct connection into the 48-in. plant effluent line. In normal operation the overflow weir diverts the settled sewage flow in excess of 10 m. g. d. into the plant effluent line and by closing the 30-in. valve the entire plant flow can be by-passed to the river after receiving primary settling.

Settled Sewage Meter.—Due to the necessity of minimizing the hydraulic losses through the plant, the only sewage flow meter is located between the overflow chamber and the aeration units, and measures only the flow of settled sewage to the aeration units. Consequently, the portion of storm flows which receives only primary settling, and is then by-passed to the river, does not appear in the plant records. The actual quantity

of sewage thus by-passed is small compared with the total flow per month.

The settled sewage meter is a Simplex air-operated type instrument connected to a 24 by 13-in. cast iron Venturi tube.

Aeration Units.—The aeration units (Figure 3) consist of four two-pass aeration tanks, in which a mixture of settled sewage and activated sludge from the final settling tanks is agitated by means of compressed air introduced at the bottom of the tanks; two final settling tanks for separating the activated sludge from the aeration tank effluent; two control houses for regulating the flows of air and sewage in each tank; and a pipe gallery for housing all the necessary piping; valves, meter tubes and metering equipment.

The aeration tanks are each 31 ft. wide, 189 ft. 6 in. long and 11 ft. 6 in. deep, with a 12-in. interior partition wall dividing the tank into two passes each 15 ft. wide and having an effective depth of 10 feet. The tank sizes provide a detention period of 4.7 hours based upon 7 m. g. d. flow with 25 per cent returned sludge.

The two final settling tanks are each 70 ft. square, with an effective depth of 10 ft. at the sides and a freeboard allowance of 18 inches. The general arrangement of the tanks and of sludge-collecting mechanisms is similar to the primary settling tanks, except that the tank effluent flows over adjustable overflow weirs. The settled sludge is drawn from the bottom of each tank separately into a sludge sump, from which it flows to a suction well in the main building, and the major portion is then returned to mix with the settled sewage flowing into the aeration tanks. The amount of activated sludge deposited in the final settling tanks, in excess of the requirements for returned sludge, is pumped to the digestion tanks directly, or is resettled in the primary settling tanks and then pumped with the primary tank sludge.

In each of the aeration control houses are located manometers to indicate the flow of air and mixed sewage in the two aeration tanks, the regulating valves controlling the air supply to the two tanks and pressure gages indicating the air pressure in the main and branch to each tank.

Digestion Tanks and Control House.—The two separate sludge digestion tanks are each 85 ft. in diameter and 22 ft. deep, provided with a solid roof to permit the collection of the liberated gas, and equipped with a Dorr stirring mechanism, and with heating coils to maintain a temperature of tank contents favorable to rapid digestion.

The digester control house consists of a brick superstructure 22 by 26 ft. in plan, built on a two-story substructure 27 ft. in diameter; it contains the control valves for the raw and digested sludge connections to the digesters, gas meters, gas-fired boiler and circulating pumps for digester heating systems, and provides space necessary for equipment required for future plant expansion.

Sludge Drying Beds.—A total of ten sludge drying beds, each 20 by 175 ft., provide 0.5 sq. ft. per capita of design population. The beds have "American-Moniger" glass covers and a system of industrial trackage, cars and gasoline locomotive is provided for sludge removal and resanding the beds.

Main Building.—The main building has a two-story brick superstructure 32 by 58 ft. in plan, housing the offices, laboratory, toilet and locker rooms on the second floor, and the blowers, switchboard and air and sewage meters on the first floor.

Three rotary type positive displacement blowers of Stacey Engineering Company make are installed, driven by synchronous motors and having capacities of 2500, 3750 and 5000 cubic feet of free air per minute, respectively. By various combinations, great flexibility can be obtained in the rate of air supplied by these blowers. The guaranteed power input averages 2.25 kw. per 100 cubic feet of free air per minute delivery against 5.5 pounds gage pressure.

In the basement are the air filters, steam heating plant, excess sludge pump and four Dayton-Dowd sewage pumps, two for return sludge and two for plant drainage.

Operation of Plant

All units were put in operation March 21, 1931, and several months were required to adjust equipment and decide upon some regular routine of operation. All units are operated up to their design capacity and any flow above this figure is by-passed to the river.

Accurate records of plant operation are available for twelve months ending August 31, 1933. This time can be divided into three approximately equal periods; during the first and last periods the entire plant was in operation, while during the middle period (January, February, March and April) the aeration units were taken out of service. This step was justified by the increase flow in the Ottawa River during the winter and spring months and resulted in a saving of about $3500 in power charges.

Quality and Quantity of Sewage.—The sewage during dry weather is of the usual domestic character and average strength; however, during storm periods the sewage comes to the plant highly diluted with storm water. Some industrial wastes have been received at the plant from time to time, usually from packing houses and oil stations. During the period from September 1, 1932, to August 31, 1933, inclusive, the average daily flow of settled sewage has been 5.41 m. g.

Automatic Bar Screen.—This unit has been in service continuously and has required very little attention. The average screenings removed have been about 5 cu. ft. daily or an average of 1 cu. ft. per million gallons.

Screenings Incinerator.—This unit is run continuously and screenings are burnt as fast as they are removed from the screen.

After the plant had been in operation about eight weeks, gas was available as fuel and by keeping one burner lighted all the time in this unit it acts as a waste gas burner and aids in keeping the screen building clean so that it makes a good appearance at all times. Very little oil has been used for fuel in this unit since the digesters began producing gas. An attempt was made during the early days of operation to burn the skimmings from the primary tanks; we found that these skimmings contained so much oil and grease that the incinerator chimney became badly cracked due to the high combustion temperatures, consequently this practice was discontinued. Skimmings are now hauled to a low place, west of the plant and periodically ignited and allowed to burn in the open.

Grit Collection.—This unit has worked very satisfactorily removing from 5 to 18 cu. ft. per day or an average of 1.16 cu. ft. per million gallons of sewage over the period from September 1, 1932, to August 31, 1933. The grit removed has been noticeably free from organic material and causes no odors even when allowed to accumulate in the grit hopper for considerable time.

Primary Tanks.—Two units 55 ft. square with rounded corners are equipped with Dorr Traction clarifiers. Some difficulty was experienced with the underspeed alarms failing to function properly. The underspeed alarm wheels were replaced by an alarm of a later design and no trouble has been experienced since that time.

It has been the practice at this plant to pump enough sludge each day to leave only about one foot of sludge on the floor at the center of the tanks. When pumping raw sludge the solids content varies from 8 to 10 per cent, but when pumping a mixture of raw and resettled excess activated sludge the solids content varies from 4 to 6.5 per cent. In order to avoid septic sludge and to reduce the effect of the return of supernatant liquor from the digesters, it has been found advisable to split the total sludge pumping time into a number of short periods.

At one time in the early months of operation, when the digestion tanks were in a foaming condition, the supernatant liquor returned to the primary tanks was almost as heavy as the sludge being pumped from the tanks. The sludge pumping periods were extended but nevertheless the amount of sludge continued to build up and finally became septic. This septic condition was carried through to the aeration units changing them from a brown to a black color. As a climax, just at the time the plant was in its worst condition, we received visitors to whom we should have liked to show a smooth-running plant. The troubles were overcome, however, by diverting the digester supernatant to a field adjacent to the plant site until the foaming had ceased.

Scum and grease is removed from the surfaces, of the tanks daily and concentrated in a well adjacent to the sludge pump station, from which it is removed and burned as described above.

Sludge Pump Station.—The Dorr diaphragm pumps which are used to pump raw sludge and resettled excess activated sludge to the digesters from the primary tanks caused a great deal of trouble for several months due to the failure of diaphragms, rubber seats and valves. The rubber seats in both suction and discharge valves seemed to lose their life and became swollen soon after being put in service. The ball valves became pitted and assumed all sorts of shapes. This trouble was finally overcome by putting bronze seats in all valve chambers and replacing the ball valves with new lead impregnated rubber balls. Since this was done no further trouble of this nature has been experienced. Considerable trouble was experienced with matches and small particles lodging on the valve seats and interfering with the pump discharge. Apparently this was due to operating with too little pump stroke as much less valve cleaning has been necessary since the pump stroke has been increased.

Aeration Units.—No difficulties were encountered in building up a body of activated sludge on the two occasions of starting up the aeration units, a characteristic brown sludge was secured in less than a week and the effect of the treatment was noticeable in the effluent on the day after aeration was started.

During the first aeration period of the year ending Aug. 31, 1933—that is the months of Sept., Oct., Nov. and Dec., 1932—the suspended solids in the aeration units were maintained at 2200 to 2600 p. p. m. by regulating the percentage of returned sludge. When aeration was resumed in the spring of 1933, this value was increased to about 3400 p. p. m. and the operation of the units has been more stable and uniform.

The settling rate of the sludge in the effluent from the aeration tanks is determined daily by noting the percentage of sludge in a one-liter graduated cylinder after a settling period of one hour. The p. p. m. of suspended solids in the aeration tank effluent is divided by 100 times the percentage of settled sludge and the resultant factor is termed the "sludge index." Little difficulty has been experienced in maintaining this value above 1.0, which figure has been reported by some plant operators to be the apparent minimum value at which they obtain satisfactory operation from the standpoint of sludge bulking. However, during the month of June, the sludge index averaged only 0.87 and for three successive days stood at 0.44, but the operating results were very good and the suspended solids in the plant effluent averaged only 3.2 p. p. m. for the month.

The pressure manometers located in the aeration control houses show the main pressure and pressure in the branch air line to each tank. It was noted that the pressure required for tank no. 4 was from $^1/_2$ to $^3/_4$

pound per square inch greater than for any of the other tanks. Since the power required, by the type of blowers in use, is directly proportional to the discharge pressure this increased pressure represented a needless waste of 10–15 per cent of the power input to the blowers. Various expedients were tried and, finally, before starting the aeration units in May a 5 per cent solution of lye was applied and allowed to filter through the aeration plates into the containers, then the air was applied forcing the solution back through the plates. This practice was repeated every day for ten days, and since that time the pressures for the various tanks are equalized and the main pressure lowered.

Final Settling Tanks.—Originally these tanks were equipped with influent baffles extending about 24 inches below the water surface. Counterflow currents were noticeable and the effluent averaged about 22 p. p. m. suspended solids. In April, 1933, a solid box baffle was constructed in each tank the entire length of the influent ports and closed on each end. The baffle extended from the water surface to within 15 inches of the tank floors. These baffles direct the aerated sewage to the bottom of the tanks and eliminate any high velocity currents. As a result the effluent has improved in clarity and the suspended solids in the effluent have averaged less than 5 p. p. m. from June through August. To illustrate the clarity of the tank contents, on a number of occasions under favorable conditions, the arms of the scraping mechanisms at the bottoms of the tanks have been visible.

The sludge blanket is maintained at a depth of about 6 inches, measured at the side walls, and the suspended solids in the return sludge average about 18,000 p. p. m. It is very apparent that the return sludge becomes thinner if the mechanisms are stopped. Undoubtedly the sludge density could be increased by increasing the depth of the sludge blanket, but we feel it is desirable to reduce the length of time that the sludge is not being aerated.

The plant effluent makes a decided contrast with the water in the river, which is usually cloudy or muddy in appearance. The effluent is being utilized for sprinkling purposes around the plant, with very good results.

During the months of January, February and March, 1933, while the aeration tanks were out of service, the settled sewage from the primary tanks was resettled in the final tanks and an additional 15 to 20 per cent of the suspended solids in the crude sewage was removed.

Digesters.—When the digesters were put in service, one tank was filled with sludge and water. A portable steam boiler was set up and steam was discharged into the sludge to bring the contents to digestion temperature as soon as possible. The pH was watched closely and remained on the alkaline side constantly, until a few days before gasification started. At this time pH dropped. Two tons of lime were added, the pH returned

to 7.5 and the tank contents began giving off gas. This tank started to foam and the gas was so plentiful we could not use all of it. A waste gas burner was installed and the excess burned. The foaming condition existed for about five weeks, and was finally eliminated by drawing down the tank contents and letting it rest. Some of the sludge from this tank was run into the second tank, which also started to foam.

After about six weeks, these tanks quited down and have acted normally ever since. The pH remains fairly constant at 7.5 to 7.8.

In the meantime, we started our gas-fired hot water circulating system and were able to get the temperature of the liquor in the digestion tanks up to 85° F. The foaming condition caused some trouble with gas lines as the foam got into the feed lines leading to the boiler and stopped up a small bleeder line on the gas pressure equalizing valve, which cause the burners under the boiler to fail to ignite after a cut-off.

The stirring mechanisms in the digesters are run continuously, and we find they are of great assistance when drawing sludge. Experience has taught us that if an attempt is made to draw sludge with the mechanism idle, only the bottom sludge around the center of the tank is removed and there is a tendency to draw thinner sludge from the overlying layers.

A layer of thick scum formed under the digester roofs soon after they were put into operation. This scum was removed several times but returned in a few days, so it was decided to leave it there. The scum has not been removed for six months and no trouble has been experienced to date from this condition.

The sampling manholes on the side of each digester, which contain the valves for taking samples from different depths in the tanks, have been equipped with suction fans, and the open overflow pipes which passed through the floor of these manholes have been covered over since the unfortunate accident which resulted in the death of two men during the early days of operation. We have made a practice since this accident of taking samples by the use of a container which is opened and allowed to fill at different depths in the tanks. The samples are taken once each month from each digester and moisture content and ash determination tests run on each sample.

The alkalinity, pH and suspended solids are run on the supernatant liquor each day.

Sludge Drying Beds.—Sludge from the digesters is run on the drying beds with an average moisture content of 93 per cent, and to an average depth of 10 to 12 inches. The average drying time has been around twenty days. The demand for this dried sludge as a fertilizer has far exceeded the supply and, for this reason, it is planned in the near future to make a charge for sludge.

Maintenance.—Very little maintenance has been necessary, the largest

item being painting. In order for the plant to retain its original appearance, it has been necessary to paint quite often. It has been our experience that aluminum paint is the most satisfactory on equipment where it can be used.

Gas Collection.—All gas produced by the digesters is metered by two Stacey rotary meters, located in the digester control house. The gas production for the year ending August 31, 1933, averaged about one cu. ft. per capita daily.

Operating Results.—The monthly averages for the twelve-month period from September, 1932, to August, 1933, inclusive, are shown in the accompanying tables. The following averages represent the year's operation:

Daily flow	5.41 m. g. d.
Cu. ft. air per gallon sewage	1.37
Detention period—aeration tanks	6.8 hours
Detention period—final tanks	2.9 hours
Daily gas production	41,090 cu. ft.
Suspended solids, crude sewage	180 p. p. m.
Suspended solids, effluent (double settled)	58 p. p. m.
Suspended solids, effluent (after aeration)	14 p. p. m.
B. O. D., 5-day, crude sewage	149 p. p. m.
B. O. D., 5-day, effluent (double settled)	106 p. p. m.
B. O. D., 5-day, effluent (after aeration)	9 p. p. m.
Dissolved oxygen, effluent (after aeration)	7.1 p. p. m.

We believe the operating records prove that the plant is turning out a good effluent but the most gratifying proof comes in the comments of the members of a golf club about 3 miles down-stream whose course is traversed by the Ottawa River. The stream formerly was foul-smelling, with floating and stranded sewage solids in evidence; now it is clean and inoffensive and has increased the natural beauty of the course. Owners of farms down-stream also have indicated their satisfaction with the present stream conditions, and one man stated that fish have returned after an absence of thirty years.

Operating Personnel.—The operating personnel consists of one superintendent, one assistant in the laboratory, three operators and three assistant operators. In addition to their duties at the treatment plant, these men are required to operate and maintain three sewage pump stations and one ejector station; also the operation of nine regulator chambers on the intercepting sewage system. Two visits each twenty-four hours are made to each of the stations.

Operating Costs.—During the year ending August 31, 1933, the total charges for operating the intercepting sewer system, pumping stations and treatment plant were $25,283.59. Of this amount $3,921.99 applied

LIMA SEWAGE TREATMENT PLANT

RESULTS OF OPERATION

Sept., 1932, through Aug., 1933

Aeration Data

Date	Sewage Flow, M. g. d. Daily Average	Precipitation, Total Inches	Temp. Sewage, ° C.	Air, Cu. Ft. Per Gal., Avg. for Month	Aeration Period, Hours, Avg. for Month	Per Cent Return Sludge	Susp. Solids, Aeration Tank Effluent P. p. m. G	Volumetric, Per Cent Sludge Return 30 Min. H	Sludge Index $\frac{G}{H \times 100}$	Secondary Settling Period, Hours
Sept. '32[4]	5.23	4.0	21	1.50	6.9	17.3	2342	20	1.17	2.9
Oct. '32[4]	5.41	5.5	18	1.24	6.5	17.6	2584	24	1.04	2.7
Nov. '32[4]	5.68	2.1	14	1.27	6.4	11.7	2221	15	1.48	2.8
Dec. '32[1,4]	5.51	4.2	12	1.26	6.7	12.6	2297	15	1.5	3.0
Jan. '33[2]	6.02	1.0	11	..	...	..	..	...	..	...
Feb. '33[2]	5.91	1.0	11	..	...	..	..	...	..	3.0
Mar. '33[2]	5.63	3.8	10	..	...	..	..	...	..	3.0
Apr. '33[3]	..	2.9	11	..	...	..	..	...	..	...
May '33[5]	6.25	5.2	14	1.29	5.6	18.8	2652	19	1.5	2.4
June '33	4.68	1.5	19	1.45	7.3	20.6	3400	43	0.87	3.1
July '33*,[4]	4.51	3.7	21	1.49	7.5	20.7	3359	20*	1.69	3.2
Aug. '33*,[4]	4.65	1.1	22	1.42	7.4	19.9	3390	20*	1.7	3.1

Notes

* 1 hour settling (% return sludge).

[1] Aeration tanks in service only first half of month.

[2] Sewage given preliminary and final settling only, no aeration.

[3] Final and aeration tanks out of service, also sewage flow meter.

[4] Excess sludge pumped to preliminary tanks.

[5] New wooden baffles—9′ 0″ high installed on influent side of final settling tanks.

ANALYSES AND COSTS

Date	Suspended Solids, P. p. m. Crude	Primary Effluent	Secondary Effluent	B. O. D., 5-Day, 20° C., P. p. m. Crude	Primary Effluent	Secondary Effluent	Over-all Per Cent Reduction Suspended Solids	B. O. D.	Nitrite Plus Nitrate Nitrogen Effluent, P. p. m.	Dissolved Oxygen, P. p. m. Crude	Final Effluent	Power Used per Month, Kw. Hr. Blowers	Misc. Plant	Total	Kw. per M. g. Treatment	Operating Cost per M. g. for Treatment
Sept. '32[1]	178	81.4	21	152	111	12.4	88.3	91.7	4.8	0.45	7.3	92,000	9,290	101,290	27.0	12.37
Oct. '32[1]	154	102	22.6	134	92	9	85.3	93.4	3.5	1.41	7.7	81,730	10,490	92,220	22.9	11.47
Nov. '32[1]	117	78	22.8	86	63	7	80.6	92	4.5	0.50	7.3	83,010	10,470	93,480	22.7	10.89
Dec. '32[1]	227	100	44.4	88	82	63	81.0	28.4	3.0	3.9	5.4	38,220	10,380	48,600	13.0	9.40
Jan. '33[2]	163	89	58	131	103	100	59.5	23.7	0.50	0.4	0.5	...	7,550	7,550	1.7	5.76
Feb. '33[2]	179	96.5	61.7	178	133	109	65.5	38.8	0.08	0.15	0.2	...	6,080	6,080	1.6	5.90
Mar. '33[2]	188	85	54	147	124	108	71.5	26.5	1.30	4.2	5.2	...	7,480	7,480	2.0	6.40
Apr. '33[3]	137	76	..	158	114	...	44.5	27.8	..	0.36	0.3	...	5,720	5,720	..	...
May '33[5]	167	100	19.6	134	106	17	88.0	87.4	2.5	0.46	6.3	77,220	10,380	87,600	22.4	12.30
June '33	209	97	3.2	221	174	8	98.6	96.4	3.0	0.14	7.1	69,130	9,950	79,080	23.6	13.63
July '33[4]	255	109	4.9	184	128	4.5	98.3	97.4	3.0	0.10	7.1	68,540	9,340	77,880	23.2	13.22
Aug. '33[1]	187	88	4.7	171	121	3.5	97.5	92.2	2.0	0.34	7.2	67,200	10,440	77,640	22.4	12.47

These figures do not include adm. charges amounting to $2436.20

SLUDGE DISPOSAL

Date	Excess Act. Sl. Pumped to Preliminary Tanks	Raw Sludge Pumped to Digester, Gallons	Excess Act. Sludge Pumped to Digester, Gallons	pH Fresh Solids	pH Digested Sludge	Temp. Sludge in Digester ° F.	Gas, Cu. Ft. per Day	Volatile Matter Dry Basis, Per Cent Fresh Solids	Volatile Matter Dry Basis, Per Cent Digested Sludge	Digested Sludge, Cu. Yd. Wet	Digested Sludge, Cu. Yd. Dry	Grit Removed, Cu. Yd.	Screenings Removed, Cu. Yd.
Sept. '32[4]	....	617,000	487,000	7.4	7.7	85	49,293	..	..	1040	344	9.5	6.5
Oct. '32[4]	748,000	783,000	....	6.9	7.4	83	52,496	70.0	58	520	83	6.8	8.3
Nov. '32[4]	489,000	594,000	....	6.9	7.4	86	45,400	65.6	42.3	460	67	7.5	6.9
Dec. '32[4]	376,000	324,700	....	7.0	7.5	88	37,600	64.4	43	..	...	3.8	6.0
Jan. '33[2]	....	288,846	....	6.9	7.7	89	38,870	62.6	48.8	..	...	6.5	6.3
Feb. '33[2]	....	186,000	....	6.8	7.7	..	36,865	64.8	44.1	..	...	2.0	6.6
Mar. '33[2]	....	325,500	....	6.9	7.6	87	34,100	59.8	45.4	1040	...	3.2	8.4
Apr. '33[3]	....	259,000	....	7.0	7.7	87	22,900	57.9	46.2	..	180	5.0	11.2
May '33[5]	....	239,750	378,500	6.8	7.9	89	25,000	50.1	45.7	440	360	3.7	5.6
June '33	....	389,750	767,000	6.9	7.6	86	56,000	61.9	43.4	740	225	4.0	4.5
July '33*[4]	682,250	651,000	....	6.8	7.5	92	50,270	62.2	45.3	900	...	12.7	4.8
Aug. '33*[4]	688,500	564,000	....	6.7	7.7	93	44,300	57.2	41.3	885	307	20.0	4.5

to the pump stations; $2,436.20 represented overhead expense such as a portion of the City Manager's salary, cost of billing and collecting sewer rental charges, insurance, etc.; and the actual cost of operation of the treatment plant was $18,925.40.

Reduced to a million gallon basis, the actual cost of operation of the treatment plant, with purchased electric power at $0.01 per kw. hr., was as follows:

For complete treatment	$12.34 m. g.
For treatment without aeration	$ 6.02 m. g.

Sewer Rental.—The cost of operation of the plant and pump stations is financed by the revenue obtained from the enactment of an ordinance under the provisions of the Ohio Sewer Rental Law. Charges are based on the amount of water used by consumers at the following rates:

$0.80 per quarter, minimum charge, for 500 cu. ft. or less
$0.15 per 1000 cu. ft. in excess of 500 cu. ft. per quarter
Rural rates, $0.90 minimum and $0.20 per 1000 cu. ft. in excess of 500 cu. ft. per quarter

In cases where industrial plants use deep wells for any purpose the discharge into the sewerage system is determined by pumping records or by any other method approved by the city, and charges are billed in accordance with the above rates. Reduced rates are applied in each case where water is used only for cooling.

When the first bills were presented, we purposely charged the industrial plants at the full rates for the amounts of well water used for cooling purposes, which they were discharging into the system, according to our survey. The total discharge from three of these plants amounted to as much as $1^1/_2$ m. g. d. Of course, we soon heard from these users and had an opportunity to show just how much it cost the city to pump and treat this waste water. Generally these users were surprised to learn how much well water they were using and some plants were able to reduce the amount or to divert the cooling water discharge to the river. In most cases we were able to agree upon charges satisfactory to both parties.

The operation of this ordinance has resulted in an average collection of approximately $4000 per month, of which 40 per cent is collected from the minimum consumers, 25 per cent from the smaller consumers in the second classification and 35 per cent from the large or industrial user. As the bills for sewage rentals are included with the water bills, it is estimated that the delinquency list amounted to about 25 per cent in the past year. In normal times the resulting collection on the above basis would be in-

creased considerably, and consideration is being given to a general lowering of the rates.

Conclusion.—We are pleased to acknowledge that the successful operation of the plant is due, in no small degree, to the coöperation extended by the City Manager, Mr. Fred C. Becker, and that the appearance of the grounds is a special tribute to his interest in the matter.

Joint Sewerage Works for Twelve Municipalities in New Jersey*

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Synopsis.—In 1904 a joint trunk sewer about 23 miles in length, with a maximum capacity of 21 m. g. d., and having a gravity outlet at tidewater, was placed in operation to provide sewerage facilities for seven municipalities lying in the Elizabeth and Rahway River Valleys in Essex and Union Counties, New Jersey.

In 1932 a trunk sewer supplementing the sewer constructed in 1902–1904, but having a capacity at the outfall of 172.5 m. g. d., more than eight times the capacity of the original sewer, was placed in operation. The supplementary sewer, in addition to serving the original municipalities, *viz.*, Irvington, Millburn, Newark, South Orange, Summit, West Orange and Vailsburg (now a part of Newark), also serves East Orange, Hillside, Maplewood, Borough of Roselle Park and the Township of Union, New Jersey. Also, through special agreement, the Joint Meeting Sewage Treatment Works serve portions of the Borough of Roselle and the City of Orange, and most of the City of Elizabeth.

The work undertaken to supplement the original sewer included, in addition to the supplementary trunk lines, the construction of a Joint Sewage Treatment Plant to serve the above named municipalities. (Figure 1.) While construction of this plant was begun in 1931, and it was planned to start operation in the summer of 1932, difficulties so universally encountered during recent times in municipal financing prevented the collection of assessments from several of the member municipalities, with consequent delays in letting of some relatively small contracts necessary to place the treatment plant in operation.

The trunk sewers having been placed in operation, and the treatment plant construction being so far advanced, I feel it is a propitious time to now record the unusual features of organization, design and construction encountered in the consummation of the joint municipal enterprise referred to in the title of this paper as the "Joint Sewerage Works for Twelve Municipalities in New Jersey."

General

History and Legislation.—The actual construction in 1902 by seven municipalities of 23 miles of trunk sewer traversing the territory of more than seven municipalities, some of them foreign to the project, is certainly fraught with interest, not only to the communities directly involved, but

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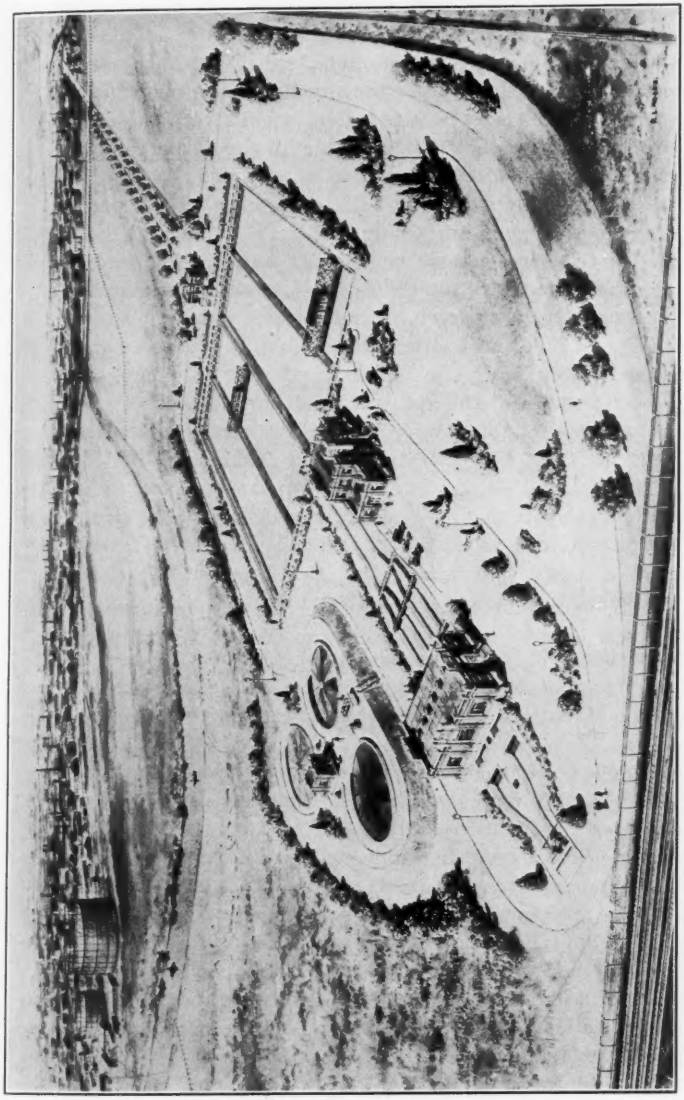

FIG. 1.—Joint Meeting Sewage Treatment Plant Serving East Orange (Part), Hillside, Irvington, Maplewood, Millburn, Newark (Part), Roselle Park, South Orange, Summit, Union (Part), West Orange, Elizabeth (Part). Plant Capacity 172.5 M. G. D.

also as an example of a distinct advance in municipal government and economic enterprise in connection with public utilities.

Being situated at considerable distances from tidewater and on streams of comparatively small flow, the question of adequate disposal of their sewage became an acute problem to the aforementioned municipalities in 1896, at which time the writer became actively connected with the project. This common need prompted these municipalities to act in combination, in consequence of which special legislation was enacted to allow the several communities interested to form a Joint Meeting for the purpose of building and maintaining an intercepting sewer.

Prior to 1920 the sewer became surcharged, so that it was necessary to plan for additional facilities for the rapidly growing communities. To that end, a report on the enlargement of the sewer was submitted by the writer in 1922. A number of towns in the tributary drainage areas of the Elizabeth and Rahway Rivers, in addition to the original group, were embraced in this report. In 1926, four years after the submittal of the report, a joint contract between the eleven municipalities named was entered into for the construction of a supplementary joint trunk sewer and disposal plant.

It is gratifying to note that many joint projects have been accomplished in the State of New Jersey since the original Joint Meeting was established, and that almost every joint scheme has been based wholly, or in part, upon the original Joint Sewer Act of 1898, and upon acts supplemental thereto.

Cost Apportionment.—Unquestionably, the greatest obstacle to the successful culmination of a joint municipal project is the determination of the proportion of cost to be borne by the various participating municipalities.

A method of apportionment of cost of the trunk sewer was devised and recommended by the writer, to the original municipalities, and accepted by them without modification.

Twenty-five years of experience indicate that this method was so fundamentally fair that in the new contract, entered into in 1926 for the supplementary sewer, the same method of apportionment of cost was adopted. The method of apportionment adopted was briefly as follows. Each municipality paid for the construction of each section in the proportion that the capacity set aside for it in such section or sections bore to the entire capacity of each section so used. The capacity set aside for each municipality in the various sections of the sewer, and consequently in the treatment plant, was not arbitrarily established, but was fixed only after conference with the various municipalities and determination of the respective capacity considered and accepted by them. The proportion of cost of constructing the treatment plant borne by each municipality was the same as its reserved

rights or capacity bore to the summation of the reserved capacities of all the member municipalities comprising the Joint Meeting.

The obvious equity of this method of assessment appeals to the average citizen, and is understandable by him. A community pays only for the part of the structure which it utilizes, and only to the extent of such use. The equitable assessments to participating towns which are situated near the outfall of the trunk sewer is apparent.

While the laws of the State of New Jersey provide for the formation of joint municipal projects, they leave the matter of cost apportionment entirely up to the municipalities so organized. As a result, several other major joint projects in New Jersey have separate methods of cost assessments. Protests that assessments have been unjust, and consequent costly delays in some of these instances have not been infrequent. On the other hand, not a single part of the Joint Meeting project being described was held up by reason of municipalities protesting unjust cost apportionment.

It is obvious that any recalcitrant municipality could have thrown a monkey-wrench into the machinery by its refusal to go along. I am of the opinion that a law giving the right to a commission, properly appointed to fix the areas of a sewerage district and assess the benefits after proper hearings upon the municipalities affected by the enterprise, would eliminate the excessive strain on those few persons obliged to secure the voluntary consent of the large number of municipalities, which by reason of their geographical and topographical location should logically be expected to become a part of any joint enterprise.

It is true that many of the states guard carefully against any infraction of the home rule principle, and that each municipality in a joint enterprise should be the sole judge as to whether or not it should become a party to any joint enterprise.

While I am a firm beliver in the general idea of home rule, there undoubtedly are cases where this home rule idea will act as a deterrent to the consummation of highly desirable enterprises.

As opposed to the method just described, we have the method adopted by Westchester County, namely, the formation of the entire county into a district, clothing the commission with power to construct such sewers as they deem best.

While hearings were held in the various municipalities, the commission had the ultimate power to weigh the force of the objections, but to proceed as they saw best. The fact that the county assumed the financial burden, and that assessments against the individual property owners did not begin for a number of years after the project was consummated acted as a preventive against any concerted opposition such as might have occurred had the citizens of the various municipalities been called upon to vote upon the

project, or if the governing bodies of the different towns had to assume the responsibility of placing a heavy burden upon their constituents.

There is much to be said in favor of a method that would deaden the force of unjust adverse criticism, but, of course, this procedure is getting far away from the home rule principle.

Growth of Communities.—When the original sewer was projected in 1898, no one could foresee the tremendous strides that have since been made in the development of certain sections of the territory served by the joint sewer.

Guesses made in 1898 by the most enthusiastic town booster as to the future growth were wide of the mark. The Town of Irvington, for instance, had a population of 5255 persons in 1898. An optimistic estimate provided for 17,500 in 1930. Actually the 1930 Federal Census shows the population of Irvington to be 56,733. Similarly, the population of Millburn increased from about 2900 in 1900 to 8300 in 1930; Maplewood from 1630 to 21,321; Summit from 5600 to 14,500; West Orange from 7000 to 24,000, and so on. The total tributary population of the eleven communities now comprising the Joint Meeting increased from 42,000 in 1900 to 244,000 in 1930. (This does not include the population of the City of Elizabeth, which has a maximum right in the trunk sewer of 40 m. g. d., and includes only 17 per cent of the entire population of East Orange, and about 12 per cent of the population of Newark.) This represents a rate of increase of about 85 per cent per decade.

Design Flow.—Based upon the analysis of the sources of sewage, and as found from the sewer gagings which were made in the course of operation of the original trunk sewer, the average rate of flow per capita was taken as 107 gallons per day. In 1930 there were 500 miles of lateral sewers in the various municipalities connected to the trunk sewer.

The estimated contributing population in 1960, for which year the design was based, is 545,500 persons. In addition to providing for this population from the member municipalities, a capacity of 40 m. g. d. was also provided for the City of Elizabeth through special contract arrangements with the Joint Meeting. The trunk sewers, together with the capacity reserved for the City of Elizabeth, was designed to carry twice the average per capita contribution (*i. e.*, $2 \times 107 = 214$ g. p. c. d.) when flowing 0.7 full.

Actual Flow.—In the construction of the original sewer, each municipality was allotted a certain capacity. It was soon discovered that unless rigid inspection was made of the laterals and house connections in the various municipalities, the actual flows would exceed their allotted capacity long before the period estimated when the capacities of the individual towns would be reached.

As maintenance engineer of the project the writer endeavored to exercise some control over the character of the construction in the various

municipalities and the use made by the various municipalities of the sewer, such as admission of roof leaders, drainage of cellars, etc., but counsel advised that the Joint Meeting could exercise no authority in these municipalities until their capacity was exceeded. This was a vicious decision and this condition soon resulted in the complete use of the capacities allotted to the towns.

In the new contract, executed in 1926, an attempt was made to remedy this condition by the inclusion in the contract of a proviso that the joint meeting had the right to inspection over all sewers and house connections in the various municipalities. This immediately became a dead letter, however, for the Joint Meeting itself refused to authorize the employment of the necessary inspection force to this end. While a serious effort was made in some towns to eliminate the entrance of storm water as much as possible, there being no one connected with the Joint Meeting with authority to act, therefore during the last seven years many of the conditions existing prior to the adoption of the new contract have been permitted to continue.

No serious effort has been made on the part of the Joint Meeting or of the municipalities to eliminate the excess water finding its way into the sewer, with the result that the new sewer is already overloaded in times of storms, and this cannot be eradicated until a substantial sum has been spent to eliminate the sources of this excess flow.

Trunk Sewers

Hydraulics of the Trunk Sewers.—The hydraulic problems involved in the design of the supplementary joint trunk sewer have presented every phase of gravity flow that can possibly be encountered in sewer design.

The supplementary trunk sewer is inter-connected with the original trunk constructed in 1902, at numerous points along its length of twenty-three miles, resulting in combined flow problems and special junctions for complete flow control. These inter-connections were necessary in order to utilize to the fullest extent the capacity of the original sewer.

Excepting in the upper stretches of the sewer on sizes 24 in. and under, the existing sewer even after 30 years of service is in excellent condition, but because of the fact that internal pressures have existed in the sewer due to the sewer operating under a head before the internal and external pressures were equalized, long stretches of the sewer have been affected and need considerable repair work.

Selection of Type of Sewer Section.—The new trunk sewer (Figure 2) varies in diameter from 24 in. to 81 in., and changes from the 81 in. circular section to a twin rectangular flume at a point about 3000 ft. from the treatment plant.

Involved in the selection of the various types of sewers were the usual considerations of the flow conditions, probable foundation conditions, depth

of cover, highway and railroad loadings and crossings, ease of construction and costs.

Range in flow was material, the design having to accommodate a minimum dry weather flow of 13 m. g. d. and a maximum of 172.5 m. g. d.

During the construction of the original sewer, careful notes were kept of the class and nature of the material encountered. As the new sewer paralleled the old, being for a large portion only 20 feet distant therefrom, these notes were of value in the design and estimates prepared for the new sewer. There were many instances, however, where in the course of construction, the material encountered only 20 feet away from the old

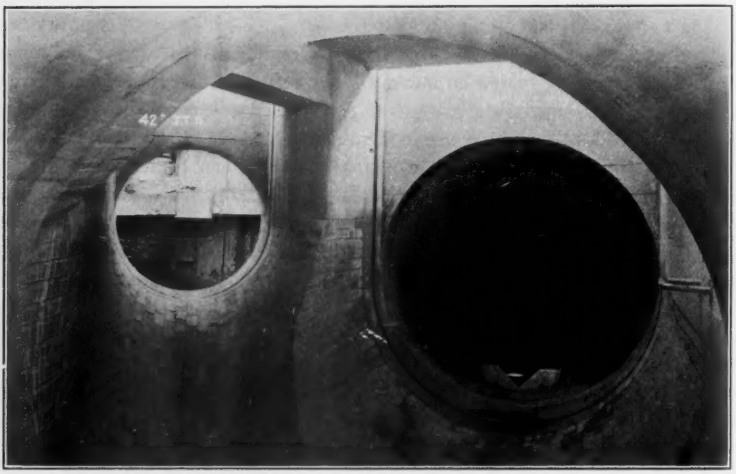

FIG. 2.—Supplementary Joint Trunk Sewer, Looking Upstream. Vauxhall Road Upper Construction Chamber. Weir Shows No Leakage After Being in Position 12 Days. Length of 75-Inch Sewer Above Weir, 4948 Feet.

sewer differed materially from that encountered when the old sewer was built. Often, for example, where hard shale was indicated as being at about the invert of the old sewer, there was no similar foundation material found in adjacent strips along the new sewer, and *vice versa*. In most instances, this was partly due to the angle of dip of the shale rock in these locations and partly to the stepping off as it approached the river.

In the lower section of the trunk sewer, comprising about three and a half miles in length, and involving pipe sizes from 72 in. in diameter to the twin rectangular flume, being the equivalent in capacity of a sewer 102 in. in diameter, wash boring in earth and core borings in rock were taken along the entire line.

This section of the trunk sewer (Section I), was mainly within the City of Elizabeth, entering the City at Monmouth Road, extending along Monmouth Road to the main line tracks of the Central Railroad of New Jersey, under the railroad to Warinanco Park, through the park to St. George's Avenue in Roselle, thence along the Elizabeth-Linden Line to and across the main line tracks of the Pennsylvania Railroad. From this point the line extends through private right of way to Brunswick Avenue. At Bayway and Brunswick, the old sewer is intercepted and carried together with the flow in the new sewer to the plant through the twin rectangular sewer, each section of which is 5 ft. 7 in. wide by 5 ft. 8 in. high, for a distance of about 3000 feet.

Over 6300 feet of Section I was in tunnel. In this portion, all borings were taken to rock, rock being generally encountered before the crown of the proposed sewer was reached. As before, every fifth boring, however, was carried below the sewer invert.

To further the objective of determining the most economical type of sewer section, contract drawings and specifications were prepared for four types of section, three of which were precast concrete pipe, and the fourth monolithic.

The types upon which bids were received may be briefly designated as (1) precast circular pipe with flat base; (2) standard circular pipe with sills and light cradle to equal the flat base type; (3) precast horseshoe shape, flat base pipe; and (4) horseshoe section of monolithic concrete. Based upon competitive bids received, the standard circular shape was found to be the most economical type and was consequently selected for the work. For the tunnel portions, the monolithic semi-circular section was selected.

From our own experience and the experience of others, reinforced concrete sewers of standard design could not be relied upon to insure a sewer without cracking. All sewers of large diameter were designed for thickness and reinforcing steel after determination of loading based mainly on the method derived by Anderson and Marston.

Dead loads were based on the formula $W=CWB^2$ ($W=$ weight on pipe per linear foot of trench; C = coefficient taking into consideration friction of material on sides of trench, together with ratio of the cover above the top of the pipe to the trench width; W = 130 lb./cu. ft. for saturated yellow clay, and B = trench width in feet a little below top of pipe).

Live loads were computed from the formula $L = CL_1$(L = loads per unit of length on pipes in trench directly under L_1; L_1 = short superloads on trench per unit of length, of length of load along trench. C = a coefficient taking into account nature of backfill; ratio of height of fill above pipe to breadth of ditch a little below top of pipe and ratio of lateral pressure to vertical and longitudinal pressure to vertical in the ditch filling).

Live loads were based on the concentration on the trench surface of two

16,000-pound wheel loads from the rear wheels of a 20-ton truck. The surface loads were assumed to be distributed over a length of trench of 20 inches, or an equivalent load per foot on the surface of 19,200 pounds. Because of the loose condition of the backfill, the longitudinal pressure along trench was assumed equal to one-half the lateral pressure of the sides of the trench.

Ultimate concrete strength was taken at 3000 lb. per sq. in. which is somewhat higher than strengths generally assumed in pipe design. It is believed that a better grade concrete, providing slightly thinner walls and slightly greater steel area, would result in more economical pipe manufacture. The value "n" was changed from 12 to 11 and working stress of concrete increased to 1125 pounds per square inch in proportion to the increase in ultimate concrete strength. From the loading to be expected, a uniformly distributed load over the top fourth of the circumference and with the pipe supported on its bottom quarter circumference, resulting in a maximum moment of $M = 0.0845\ Wd$ was used.

A study was made regarding the relative economy of designing pipe for a 15-foot cut, using cradles below this depth, and also for designing all pipe for a 20-foot cut, and it was found that considerable economy could be secured by building all pipe strong enough for the 20-foot cut thereby eliminating a substantial amount of cradle which, on large size pipe, is expensive.

FINAL THICKNESSES ADOPTED

0 to 20 ft. Cuts—Designed for 20 ft. Cut

Diameter, In.	Loading, Lb./Lin. Ft.	Moment, Ft. Lb.	Depth to Steel, In.	Pipe Thickness, In.	Area Steel, Sq. In./Ft. Pipe
66	17,000	7,900	6 3/4	8	0.81
72	17,500	8,860	7	8 1/4	0.864
75	17,810	9,410	7 1/4	8 1/2	0.89
81	17,900	10,220	7 1/2	8 3/4	0.93

The section of the trunk sewer extending a distance of about a mile upstream from the outfall terminus required particular consideration in regard to selection of type of section. This portion of the sewer was to have a capacity of 172.5 m. g. d. and was to take the combined flow from the old and new trunk sewer junctions. The limited slope and comparatively shallow depth available led to the adoption of a wide and shallow flume comprising two compartments as above described.

Another factor in the selection of the rectangular section for this portion of the line was to avoid any undesirable surcharge of the existing intercepted sewer at Bayway Avenue crossing. The twin section designed to provide approximately the same velocity as the circular sewer above, and being much wider than the circular pipe, can carry the combined capacity of the old and new sewers with substantially less depth than is necessary

in the circular pipe, thereby reducing to a negligible degree the surcharge of the old sewer.

Sections I and II of the supplementary sewer involved the crossing of three main trunk line railroads carrying heavy rapid and frequent traffic from and to New York City. Tunnel construction was adopted for these crossings, involving the use of segmental steel liner plates. Plate thickness of $^3/_8$ in. was found most satisfactory. Excavation in two of these crossings was carried on by means of poling plates, while a compressed air-driven shield was used in the third. Precast circular pipe, skidded into position on steel rails set to line and grade, was selected for the crossings. Use of precast pipe eliminated the effect upon setting that would be encountered in pipe cast in place, due to vibration from overhead traffic which proceeded throughout the work with no "slow orders."

As liner plates were completed, grout under pressure was applied to fill the voids between the liner plates and the original ground.

After the pipe was placed in the tunnel, grout under pressure was placed between the plates and the pipe.

Under the C. R. R. of N. J. tracks, a twin circular sewer was used, and in the driving of the second pipe we had an opportunity of detecting the extent to which the grout had permeated the ground.

These pipes were laid 12 inches apart, and the grout was found to just reach the surface of the second pipe. On the outside grouting, that is, between plates and embankment, a weak fluid grout about $1:4^1/_2$ was used. On the interior grout, a $1:2^1/_2$ mixture was adopted.

Coefficients and Head Losses.—Sewers have been designed on the basis of Kutter's formula, with a value of "n" equal to 0.013 on tangents and a value of 0.018 on curves. The use of the higher roughness coefficients on curves results in slopes nearly twice the slopes on tangents and further provides the additional drop in the sewer at the point required. Velocities varying from four to six feet per second, with a sewer flowing full, are provided for.

Curves were constructed with a radius of 70 feet for the rectangular section, and with a radius of five times the diameter for circular pipe.

Head requirements, due to velocity changes, were provided for in the design. In determining the elevations of the hydraulic gradient, allowances were also made for transition losses due to changed pipe diameters, sewer sections, depressed sections, special junctions and so on. Losses at transitions were kept down to a minimum by designing transitions which would provide for practically constant velocity throughout the change from one section to another.

While this is a provision which should be made in all good designs, the omission of this refinement is only too evident in many sewer systems examined by the writer.

Special Structures.—Mainly due to the inter-connections and combined flow conditions of the old and supplementary trunk lines, a number of special structures, principally junction chambers, were constructed. Provisions for manipulating the flow at such junctions were made by inserting stop log guides at points of vantage. At the principal junctions, where the flow manipulations were likely to be carried on more frequently, hand-operated sluice gates were installed.

The most interesting group of junction chambers are located at Union Avenue, near the Elizabeth River, in Union Township. At this point the flows from Sections 3, 4, 5 and 6 of both the old and new sewers are brought together. Venturi meters, described in a later part of this paper, are also provided at this point, to measure the contributions from Summit, Millburn, the Oranges, Maplewood, Irvington and Newark. These structures happen to be located in a restricted residential zoning area, and consequently the building located over the principal junction and housing the Venturi meter registers (and later, emergency chlorinating equipment) was architecturally treated to conform with the type of building planned for this area.

Unfortunately, this particular location, where it was necessary to construct some of the most important special structures, was found to be underlaid with a bed of quicksand some 40 to 50 ft. deep. Coupled with the handling of this material was the necessity of maintaining the flow in the old structures by constructing temporary timber flumes. At times the flow in the existing sewers at this point reached a rate of 50 m. g. d.

Measuring Devices.—In a joint project of the type described herein, where the various member muncipalities have contracted for certain maximum rights, and where maintenance costs paid by the members depend entirely on usage, the matter of measurment of flow contribution is of considerable importance. In the original sewer, flow contributions were determined from chart records obtained through the use of automatic depth recorders at pertinent points along the sewer. The introduction of additional members, plus the added miles of inter-connected trunk sewers, complicates the problem.

While the adoption of automatic recording and totalizing instruments suitable for all conditions of flow encountered at the numerous measuring stations would prove to be a prohibitive expense their use at particular points are almost mandatory. In this instance, Venturi meters have been selected for use at (1) the so-called Union Avenue Junction Chamber, (2) The Elizabeth City Line and (3) The treatment plant.

At the first named location, two Venturi meters each 30 by 48 in., having each a maximum capacity of 58 m. g. d., have been built. At the Elizabeth Line, one meter, 48 by 75 in., with 130 m. g. d. maximum capacity, is installed, and at the plant, two Simplex meters each 84 by 42 in with a com-

bined maximum capacity of 194 m. g. d., are installed. The hydraulic characteristics in the design of treatment plant meters are described in a latter part of this paper, and cover also the design of the other meters mentioned.

In general, the measurement of the flows at other points along the line will be accomplished either through the use of weirs and simple stage recorders originally used, including, of course, the refinements in their design and construction introduced during the last thirty years, or Venturi flumes.

The trunk line Venturi meters are provided with underground chambers of the two-story type, the tubes and dewatering pump in the lower compartment, with the registering mechanism and motor for the vertical pump on the upper floor. By-passes have been provided on these meters.

A general objection to Venturi meters located on the main line of flow is that because of the constricted throat section, and the depression of the meter below the hydraulic gradient, gases carried along the sewage surface are prevented from continuing their passage and are found to accumulate above the meter entrance. Provision of perforated manhole covers at each end of the meter prevents to some degree the dangerous accumulation of such gases at these points.

Use of the Venturi flumes of the Parshall type for sewage has received attention in trunk sewer work in various parts of the country. The writer has installed some six of these flumes, four of which are located on the trunk sewer described. While these flumes eliminate some of the objections of the Venturi meter in sewage work, and can be constructed at very much lower costs, the greatest difficulty has been that of obtaining suitable automatic registering integrating devices at reasonable cost. Furthermore, these flumes must be carefully calibrated before the recording devices are designed, and under certain conditions of use it is difficult to perform the calibration tests. Use of models in hydraulic laboratories can of course, be resorted to. This method involves additional expense, and, of course, it is sometimes difficult to duplicate, in the laboratory, the actual field conditions.

Odor Condition.—In September, 1932, the new trunk sewer, though not completed to the terminus at Arthur Kill, because of the uncompleted treatment plant structures, was nevertheless placed into operation to its junction with the old trunk line at Bayway and Brunswick Avenue. At this point the flows from both the old and new lines were discharged under pressure into the old outfall and thence into Arthur Kill at the foot of Bayway Avenue. Though the capcity of the old outfall sewer is only 21 m. g. d. flowing full, the new flow it was forced to take was many times its capacity. The additional head required to force this greater quantity through the old sewer was built up by the backing up of the sewage in manholes, to

overflowing at street surfaces at low points. Under these conditions, ventilation of long sections of the line was completely cut off.

While the old trunk sewer in its many years of operation was surprisingly free from odor, complaints regarding odors were frequent during the first summer of operation of the combined new and old lines, due mainly to the cutting off of ventilation by choking of the outfall as described.

During the second summer of operation, 1933, relief from surcharge of the old outfall with return to design conditions was obtained together with free ventilation by constructing a temporary bypass flume above the plant to the Elizabeth River, pending the completion of the plant. Since this method of operation was put into effect there have been no odor complaints, and consequently no special odor control has since been necessary.

Chlorination for Odor Control.—Odor complaints in the residential sections of the City of Elizabeth, through which the lower three miles of trunk sewers passed, attendant at the beginning of the trunk sewer operations, resulted in a complete survey and study of the odor conditions and means of control. In September, 1932, four 720-lb. and one 360-lb. Wallace & Tiernan Vacuum Chlorinators were installed at the Union Avenue Junction Chamber, about six miles above the outfall. The machines were housed in the Main Junction Chamber Building, while chlorine was fed to the machines from a battery of five one-ton containers on a platform in the rear of the building.

The chlorine demand of the sewage was found to vary from 10 to 20 p. p. m. Some difficulty was encountered at first in determining the minimum dose required. Where the object in chlorination is only odor control the chlorine demand does not have to be satisfied, as it is not necessary to sterilize the sewage completely. The chlorine dosage if determined from the chlorine demand tests therefore results in the use of more chlorine than is necessary. Sufficient chlorine, however, must be added to kill the hydrogen sulphide-producing bacteria. In long trunk sewers this factor is of particular importance. Furthermore, between the point of chlorination and discharge into the receiving waters, additional quantities of sewage are received. The determination of the chlorine dose by the sulphide measurement, while resulting in a much smaller dose than that determined by the chlorine demand, results, therefore, in underdosing with consequent poor results.

To A. E. Griffin, research chemist of the Wallace & Tiernan Company, is due the credit for developing the method of odor control in this work which met with practical results. The technique developed was to chlorinate to the point where the methylene blue color lasted at least two hours in a sample taken at the outfall. Based upon this method, complete odor elimination was obtained with the chlorine dose reduced to only 8 p. p. m from the average of about 15 p. p. m. as determined by chlorine demand tests.

The methylene blue test has been described by Mr. Griffin in the technical literature, and is quoted below from his paper on the subject. (*Water Works & Sewerage*, June, 1933.)

"Methylene blue becomes decolorized in the presence of hydrogen sulphide and reducing bacteria. Thus so long as the blue color persists in a sample containing methylene blue, no odor can exist, and this test makes a very neat indicator of the presence of sulphides in sewage. Briefly, 0.5 cc. of a 0.10 per cent methylene blue solution is added to 250 cc. of sewage in a glass stoppered bottle, care being taken that no air is left between the liquid and stopper. The bottle is then stored in the dark at room temperature of about 20° C. The progress of the color disappearance is noted at intervals. If the blue color holds for four hours, no odors will appear within that period, provided the sewage passing through plant or sewer is not reseeded within that time with sulphate-splitting organisms. Where there is a possibility of reseeding, as in a trunk sewer, chlorine should be added at the designated point until the methylene blue color holds for at least two hours at the point of discharge, or at some critical point down sewer below the chlorine application."

Cost of Chlorination.—Based upon a dosage of 8 p. p. m. of chlorine, cost of chlorination for odor control for a period of ninety days, during which time approximately 1500 million gallons of sewage was treated, averaged $1.80 per million gallons of sewage treated. Of this amount, 42¢, or over 23 per cent, represents the cost of water necessay for the operation of the machines and application of the chlorine, while $1.38 represents cost of chlorine, including freight and trucking of ton containers. Cost data published on chlorination generally give little if any attention to the portion of the cost represented by the purchase or otherwise procuring of water for operation. The average water consumption over the entire three-month period of operation in this case was 24 g. p. m.; the total quantity used amounting to 410,000 cu. ft., which is an appreciable quantity. The installation of a pressure regulating valve in the water supply line to the chlorinators, thus regulating the fluctuating pressures from the city water mains on the machines within one pound, resulted in a more economical use of water.

Sewer Explosion.—It may be worthy of mention that on January 24, 1933, an explosion occurred in the sewer at the Main Junction Chamber on Union Avenue. The building above the chamber houses the chlorinating machines, the Venturi meter registers and the sewer sluice gate controls.

While the incident has been referred to as an explosion, the evidence afterward secured would indicate that what happened was more in the nature of a fire in the sewer junction chamber rather than an explosion.

The explosion, or fire, ostensibly was ignited by a spark originating in the junction chamber, although this matter is not fully determined.

From the thorough investigation which followed, it was found that gasoline and other inflammable wastes were being discharged into the sewer, and the explosion, the expense for repairs of which was limited to only $2000, was a warning of what might happen if the source of the inflammable material was not eliminated. Following this investigation, the writer prepared a form of ordinance which was in general accepted by the contributing municipalities, making it illegal to discharge inflammable material into the sewer, and providing for the separation of gasoline, oils, grease, etc., from the sewage before discharging into local sewer systems.

Sewage Treatment Plant

Condition of Receiving Waters.—The joint outlet sewer discharges into Arthur Kill in Elizabeth in the immediate vicinity of the Goethals Bridge. The tidal waters of Arthur Kill receive not only the sewage from the Elizabeth River Valley, but also from the Rahway River Valley and a portion of the sewage carried back, by tidal action, from the Raritan River Valley below Perth Amboy. In addition to receiving organic wastes, these harbor waters also receive many industrial wastes, particularly oils and chemicals.

The Tri-State Treaty Commission, in its 1932 report, shows the equivalent contributing population to Arthur Kill at Perth Amboy to be 404,507 and the equivalent untreated sewage discharging in 1930 into these waters to be 51.79 m. g. d. The dilution ratio available for sewage under the present conditions is only 0.73 to 1, considering land water only, and 1.25 to 1, considering land and sea water. Stated another way, according to data contained in this paper, the dilution now available in Arthur Kill at Perth Amboy, per 1000 population, considering land and sea water, is 0.25 c. f. s.

Observations on dissolved oxygen saturation in the receiving waters at selected stations indicate the following:

Station	Minimum Percentage Saturation of D. O.	
	1903	1931
Kill Van Kull		
Shooters Island	78	24
Arthur Kill		
Opposite Fresh Kills	71	11
Tottenville Ferry	100	43

Obviously, these waters have no longer sufficient capacity for the disposal of sewage discharged therein, under existing conditions. Furthermore, if no treatment is provided for the sewage now reaching the harbor waters, conditions estimated to exist in 1970 will be intolerable.

As a direct result, the communities in the Elizabeth, Rahway and Raritan River Valleys are under State Board of Health orders to stop pollution of the harbor waters. The municipalities in the Elizabeth River Valley, that is, the Joint Meeting for certain municipalities in Essex and Union Counties, New Jersey, were among the first to take steps to comply with these orders, and are now preparing to place into operation the treatment plant constructed for this purpose at Elizabeth, N. J. This plant is located on a 28-acre plot of land bounded in general by the Elizabethport-Perth Amboy Branch of the Central R. R. of N. J., the Elizabeth River, South First Street and Brighton Street (near Goethals Bridge).

Degree of Treatment Provided.—In requesting the municipalities to discontinue the pollution of the receiving waters, the New Jersey State Board of Health requirements (1926) for the ultimate treatment to which the sewage from the joint outlet would have to be subjected "is to be a method of sedimentation and disinfection."

To conform to State Health Department requirements the treatment selected is to provide (1) screening by means of coarse bar racks, mechanically cleaned bar screens, having $^3/_4$ in. clear space between bars, (2) grit removal with mechanical equipment for removal from chambers and disposal of same, (3) sedimentation with a detention period of four hours, (4) continuous sludge removal, (5) temporary sludge storage with ultimate sludge disposal at sea, (6) ultimate disinfection of plant effluent.

While a great number of plants throughout the country provide only two hours and less for detention of sewage in sedimentation basins, and obtain, in many instances, good removal of suspended solids, the requirements of the New Jersey State Department of Health, at about the time this plant was being designed, were changed so that the four-hour detention period became mandatory and had to be adopted in the design.

Excepting the settling tanks, which, at four hours detention now provide for an average daily flow of 50 m. g. d., the remaining essential parts of the plant which would be difficult of duplication in the future, are designed for a maximum capacity of 172.5 m. g. d. Excepting the sludge works and some 450 feet of outfall sewer, all units of the plant, including the superstructures, are now substantially completed.

General Plant Hydraulics.—There are several controlling factors which fix the elevation of the crown of the sewer entering the plant, and prevent it from being raised above the level adopted. The relatively low elevation of the street surface on the old joint trunk sewer at the Pennsylvania Railroad crossing over Bayway, the low elevation of the crown of the joint trunk sewer at the point where it is intercepted by the new sewer at Brunswick Avenue and Bayway, the relatively low elevation of Trenton Avenue, and the elevation of the Central R. R. of N. J. tracks just above the plant, all tend to depress the crown of the sewer. All the above-

mentioned fixed points prevent the construction of a larger sewer on a flatter grade entering the plant, and the consequent gain in elevation above mean sea level which would thereby be obtained.

As a result of these restrictions, the crown of the trunk sewer entering the plant is at Elevation 7.81, and the following tide data demonstrates the comparatively small loss of head that is available under maximum tide conditions.

The range of the tide is illustrated in the following tabulation, with all elevations referred to mean sea level at Sandy Hook as a datum.

	Elevation, Based on Mean Sea Level at Sandy Hook
Mean low water	−2.35
Mean high water	+2.35
Maximum predicted tide for ordinary year	+3.00
Highest observed recently	+6.70
Probable maximum high tide	+7.00

It is obvious that with maximum tide elevations, the loss of head available through the plant is comparatively small. Combined with this condition it has been necessary to provide for a very wide range in flow. This range varies from the present minimum flow of 13 m. g. d. to a maximum future flow of 172.5 m. g. d. or a ratio of 1 to 13.

The limited head available brings about two conditions: First, it necessitates rather large flumes in order to keep velocities at maximum flow reasonably low and thereby reduce velocity head losses. Second, an interrelated result is that in order to pass the present minimum flows through the plant at velocities high enough to prevent subsidence of solids where not desired, a considerable range of adjustment in effluent weir level in settling tanks is necessary. The present range for the setting of the effluent weirs is between elevation +3.0 and +5.0 In the future when the flow is sufficient to provide adequate velocities with a higher setting, the weirs can be set at elevation +6.40.

In order to reduce the head losses through the plant to a minimum, it was found necessary to avoid sudden increases and decreases in waterway area, as the sewage passes from one unit to the other. In addition to the selection of proper velocities at various points throughout the plant, carefully planned transitions and smooth curves were adopted, so as to minimize the losses.

The plant is so designed that it affords great flexibility of operation. It is essential for low flow conditions that the flow be diverted into one influent channel, which in connection with the adjustability of the weir provides easy means of maintaining proper self-cleansing velocities in the various influent structures. In case repairs and other incidental work has

to be done at any point in the plant, the flow can be shifted from one-half of the plant to the other.

Swing Gate.—In order to obtain the required flexibility of flow a motor-operated swing gate has been installed, which may close in three positions. (Figure 3.) This large gate, 6 by 9 feet in dimension, is very similar to a ship's rudder and does the job of dividing the flow in the two sides of the plant, or can be moved into position for diverting the flow from the two rectangular flumes to either side of the plant. In doing this job, this gate takes the place of three vertical sluice gates.

The gate, which is hollow inside, is constructed of Everdur plates $^1/_4$ in.

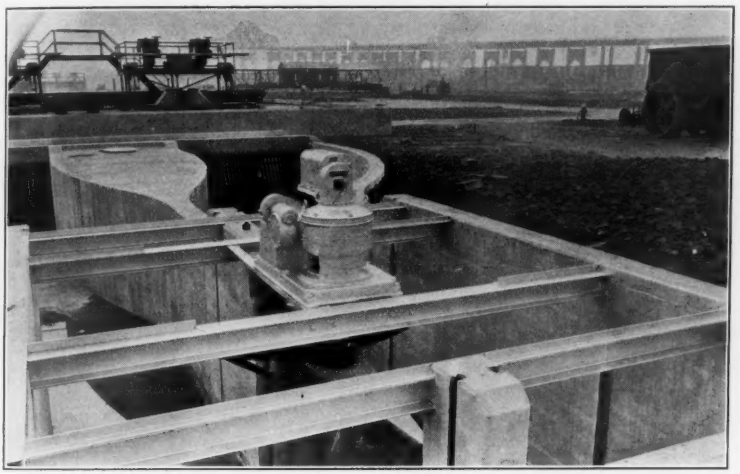

FIG. 3.—Supplementary Joint Trunk Sewer. Motor Operated Swing Gate.

thick welded together. It is hung from the top bearing, the bottom bearing which is the sleeve type, acting only as a guide bearing. The top bearing is a SKF roller bearing.

The gate is propelled by a one-horsepower motor, connected to the gate through a Foote reduction gear unit.

Coarse Racks.—Each of the two coarse bar racks has a gross width of 12 feet, a net clear width of 10.5 feet and a submerged depth at maximum flow of 5.60 feet. Bars provide a clear opening of $3^1/_2$ inches. The velocity through the net opening, under maximum flow conditions (that is, one-half of 172.5 m. g. d. for each rack) is 2.29 feet per second. The estimated net loss for this condition is 0.15 feet. Agitator piping, supplied from the air distribution system running through the plant, is installed at

these coarse bar racks in order to throw into suspension any grit or other matter which may tend to settle out in front of the racks.

Mechanically Cleaned Racks.—The rack for each of the two mechanically cleaned bar racks has a gross width of 12 feet, with a total net width of 8 feet. Bars provide a clear opening of $^3/_4$ inch. The submerged height at maximum flow is 5.74 feet. The velocity through the net area, with a maximum flow of one-half of 172.5 m. g. d. for each rack, is 2.92 feet per second. The net head loss under these conditions is estimated to be 0.30 feet.

Grit Chambers.—Four grit chambers (Figure 4) are provided to take care of the total future flow, and provision has been made to obtain clean and

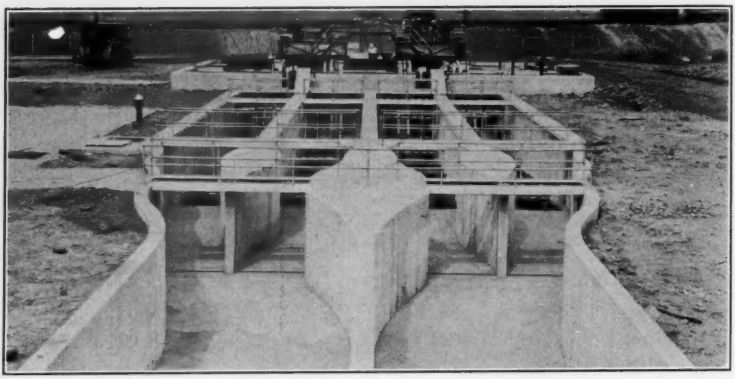

FIG. 4.—Grit Chambers. Looking Upstream.

inoffensive grit both by regulation and control of velocity, and by means of mechanical equipment for removing and washing the grit. The control of velocities will be affected by throttling the flow through the chambers by means of motor-operated sluice gates at the influent end of the chambers.

The grit chambers are designed for a velocity of 0.75 ft. per second, and a detention period of approximately 68 seconds for maximum flow conditions. For less flow, approximately the same velocity can be obtained by diverting the flow only through one, two or three chambers. Provisions are made so that any of the grit chambers can be dewatered by pumping, for inspection and incidental repairs to the grit removing equipment.

Settling Tanks.—While the trunk sewer, the influent channels and grit chambers are designed for a maximum flow of 172.5 m. g. d. the present four settling tank units are designed for 50 m. g. d. on the basis of a de-

tention period of four hours. (Figue 5.) Each tank is 75 ft. in width and 280 ft. in length; the average depth below maximum high water is 13.85 feet.

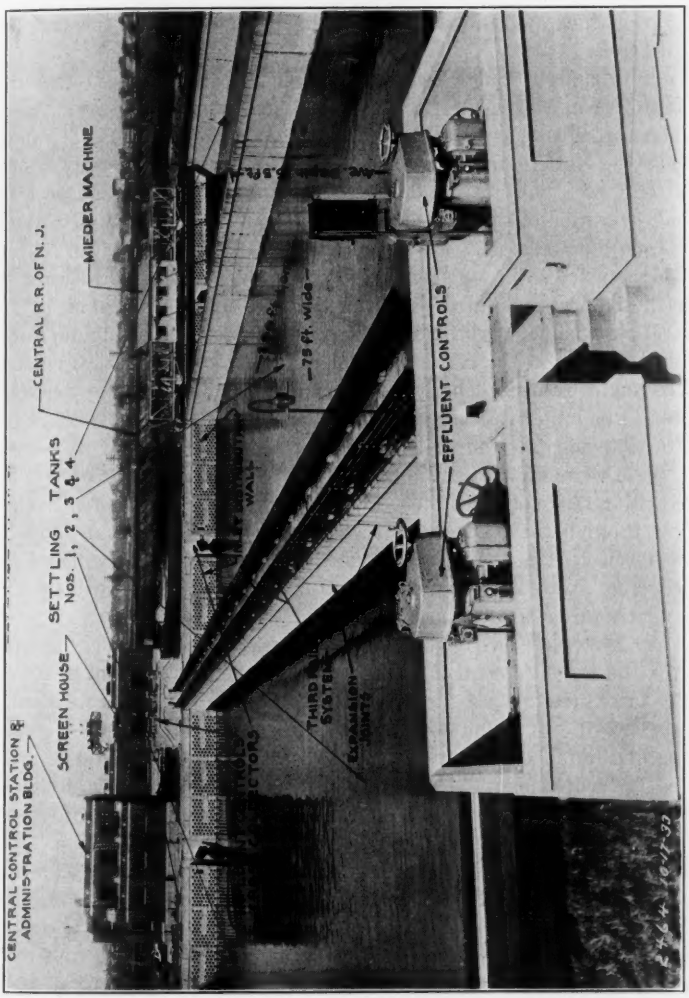
CENTRAL CONTROL STATION & ADMINISTRATION BLDG.
SCREEN HOUSE
SETTLING TANKS Nos. 1, 2, 3 & 4
CENTRAL R.R. OF N. J.
MIEDER MACHINE
75 ft. wide
EFFLUENT CONTROLS

FIG. 5.—Joint Meeting Plant. Control Station, Administration Building, Screen House and Settling Tanks.

This design was adopted because it is a comparatively easy task to add settling capacity by building new tanks, while on the other hand it was found impractical and costly not to build the influent structures to carry

the full future capacity. It is possible also that the 4-hr. detention period, as called for by the State Board of Health of New Jersey, may be revised in the future, as is the present trend elsewhere.

The flow to each of the four units will be regulated by motor-operated sluice gates which are built on a platform at the entrance to the tank influent flumes.

Sewage brought through the influent flumes will pass into individual distributing channels, each separately controlled by motor-operated gates, and then through open ports and through a perforated diffusion wall to distribute the flow entering the tanks. The theory of this design is to subdivide the flow equally to the tanks in use at any one time, and prevent unequal deposition of sludge. The diffusion wall is completely perforated with 8-inch diameter holes approximately $10^3/_8$ inches center to center. Some of these holes will be plugged or kept free, as may be required to obtain the best possible distribution of the flow entering the tank.

A steel plate baffle, having a submergence of 8 inches at minimum water level, is provided on the effluent end of the tanks, together with effluent weirs having a total net length of 54 feet in each tank. These weirs are designed to be adjustable between elevation 3 and elevation 6.85, and because of the wide range of adjustment required, it is not feasible to construct these weirs for the full range at the present time, but they are installed with a range of adjustment from elevation 3 to elevation 5. When the flow through the plant is large enough to allow the maintenance of sufficient velocities in the influent channels, the effluent ports will be filled with concrete up to approximately elevation 5, and the weirs will then be permanently raised to their new position.

Venturi Meters.—Two 84 by 42 in. Venturi meters, designed particularly for the measurement of sewage, are installed in the outfall sewer. Each of these meters has a capacity range for accurate measurement varying between 15 c. f. s. and 150 c. f. s. These meters are unique in their features and furnished perhaps one of the most interesting hydraulic problems on the whole plant. Usually the controlling point in the design of the Venturi meter is the drop of the hydraulic gradient at the throat section. However, this was not the case with the meters in question. The low flow that had to be provided for in connection with a possible drawdown curve in the outfall sewer, due to low tide, was the controlling feature in these low-head Venturi meters. In other words, it was necessary to establish the crown elevation of the inlet tube where the up-stream pressure ring is located in such a relation to the invert of the outfall sewer that the up-stream ring for all conditions of flow was filled with sewage. The entrance to the meter and the down-stream tapered transitions were carefully designed with smooth curves, and in connection with the proportioning of inlet and throat diameters, it was feasible to reduce the head-

loss to a minimum. With maximum flow of 150 c. f. s. through one meter, it is expected that the loss of head will not exceed 0.5 ft., and that the accuracy of measurement will be within 2 per cent with the range of flow from 15 c. f. s. to 150 c. f. s. Although these two meters have not been tested to verify the loss and accuracy, we have every reason to believe that our predictions will hold, because of the fact that similar meters up to 75 by 48 in. are installed on the trunk sewers now in use, on which the loss of head and accuracy through careful tests were found to check the computations very closely.

Outfall Sewer.—The outfall sewer consists of a twin rectangular section 7.25 feet in width, with a height at the side walls of 6.25 feet, and a center height of 6.5 feet. This section extends for a distance of 1750 feet from the down-stream end of the Venturi meter transition on a 0.03 per cent grade, and is connected with a terminal chamber of the dock line at Arthur Kill.

The sewage will be discharged downward through this terminal chamber and out into Arthur Kill through two ports, into a depth of 26 feet of water. The velocity through the ports, at maximum flow, will be 2.32 feet per second.

To provide for proper dispersion of the sewage in the Sound, the area in front of the port will be dredged to elevation −28, with a sufficient slope back to the existing surface of the channel bottom to prevent filling subsequent to dredging.

To control the period of detention in the outfall sewer between the plant and the terminal chamber to approximately a period of 30 minutes, and thereby insure thorough chlorination before discharging into the Sound, stop planks are provided for at the entrance to the terminal chamber, causing the outfall sewer to serve also as a chlorine detention tank.

Chlorination.—Although the application of chlorine is not required as yet by the State Board of Health, it was considered advisable to make provisions for chlorine treatment of the effluent at the present time. Space has been reserved in the Venturi chamber superstructure for the installation of chlorinating machines. Only chlorine feed equipment will be installed in this building, inasmuch as a chlorine storage building has been designed and can easily be constructed independent of existing structures and adjacent to the future railroad siding. The cylinders will be handled direct from the freight cars to the storage house, and the chlorine will be piped to the equipment at the point of application in the Venturi chamber. This chamber is partitioned off into two rooms by a tight wall, one housing the Venturi meter register-indicator recorders and dewatering and sump pump motors, and the other the chlorine feed machines. The latter room has been provided with a proper ventilation arrangement and is also tied up to the main feeder of the water supply system for the plant.

Mechanical Equipment.—Prior to the final designs for the various plant structures, bids were received on the major mechanical equipment for the settling tanks, grit chambers and screens.

In selecting the most favorable bid, consideration was given not only to the prices bid for furnishing and installation of the equipment, but also to the comparative cost of the containing structures required by each type of equipment.

Including equipment, installation and structural costs of containing structures, the bid of the Link Belt Company for rectangular settling tank equipment of the Mieder type, with Link Belt grit chamber and bar screen equipment, was the lowest of the bids submitted by three manufacturers, and was selected as the most favorable.

The Link Belt grit chamber equipment, bar screen equipment and the sludge sump cross collectors are well known in the sewage works field, and will not be described here. It is believed, however, that the Mieder type settling tank equipment, being the first of its kind in America, may be of general interest and so will be discussed in some detail.

Mieder Sludge Removal and Skimming Mechanism.—The Mieder mechanism consists essentially of a 75-ft. bridge spanning the tank and driven along rails on the tank walls by a drive unit consisting of a 10 hp. electric motor, reducing mechanism and variable speed transmission device.

A scraper is attached to the bridge by swiveled pipes, and can be raised or lowered for use in skimming or scraping sludge as required.

At the effluent end of the tanks, transfer tracks for moving the equipment from one tank to another are provided. Each machine is to care for two settling tank units. The machines are provided with transfer trucks with wheels which can be raised or lowered by the drive unit in transfer operations.

By means of the variable speed transmission device, the mechanism can be operated at any desired speed between the range of one and seventy-five feet per minute.

Best operating speeds can be determined only after the plant is in operation but will be approximately as follows:

Operation	Speed, Ft./Min.
Running free	75
Skimming	10
Scraping sludge	2 to 3

Some of the salient features of the Mieder type settling tank cleaning mechanism are:

1. *Adaptability to enlargement of plant without additional equipment cost.*—Because of the provision for transfer from one tank to another, this equipment, operating at the above speeds, can complete a cycle of operation of

three tanks in about 9 hours. During this cycle, three tanks (280 feet in length) are traversed, and three skimming, three sludge scraping and four transfer operations are performed. The equipment is provided with a limit switch so that the operator may leave the mechanism and the apparatus will automatically stop at the end of the run.

It is obvious, therefore, that the two units now built for four tanks can serve a plant of considerable additional capacity before added equipment units become necessary.

2. *Adaptability to insure uninterrupted service of settling tanks.*—If mechanical trouble develops, tanks may still be kept in operation, whereas with some types of equipment, the tank must immediately be put out of service.

3. *Ease of starting with accumulation of sludge in tank bottom.*

4. *Adaptability to skimming.*—This feature becomes more important where there is a likelihood of presence of floating material such as oil, grease or distillation by-products.

5. *Short length of sludge lines.*—Rectangular tank layouts, with sludge sumps at the ends of the tanks instead of at the center, require a considerably shorter length of sludge line with consequent reduction in sources of troublesome plant operating features.

6. *Working parts above sewage.*—In the Mieder mechanism all moving parts are above the sewage, thereby being readily accessible for repair and adjustment.

Electrical Operation of Mieder Mechanism.—The Mieder machines receive their power from a 440 volt, 3 phase, 3 rail contact rail system, through shoes mounted on the crane. The machines are equipped with two motors, *viz.*, one 7.5 hp. for general operation of the crane, and one 8.9 hp. for operation of the hoist.

After each operation of the machines is started, the operator may leave the crane and go about some other work, if necessary, for when the machine reaches the end of an operation, a limit switch shuts down the motor. The operator must then return to start the crane for another operation.

The machines are equipped with lights, both for the operating house mounted on the traveling bridge and for lighting the sewage surface in front of the crane.

Use of Mieder Equipment Abroad.—While the installation of Mieder machines in the Joint Meeting Treatment Plant is the first installation in the country, this equipment had been in successful operation in Leipzig, Germany, for over two years up to 1930, when it was selected for the Joint Meeting plant. An inspection of the operation of this unit at the Leipzig plant was made by an assistant in my office in October, 1929, and was found most satisfactory. (An article describing the methods of disposal at Leipzig by Dr. William Rudolfs, including a description of the Mieder

mechanism there installed, appeared in the July, 1930, issue of *Public Works*.)

Sludge Disposal.—At the present time, all units of the plant are completed with the exception of the sludge works. Ultimate disposal of sludge at sea is to be adopted. Barge loads will be in the neighborhood of 3000 tons which, for the early years of operation, will represent about two weeks sludge accumulation. Sludge storage tanks will provide a capacity of about 150 per cent of a barge load to provide for a possible interruption of barging service and to assure the economy possible only with a full loading of the barges on each trip. The tanks will be provided with proper decantation valves and equipment.

To accommodate the sludge barge, a deep water dock about 300 feet long will be constructed at the terminal chamber in Arthur Kill. The present channel will have to be dredged to provide a depth of about 28 feet below mean low water to handle the loaded barges.

Miscellaneous Plant Equipment

Scum Ejectors.—During skimming operations, after the scum is brought to the effluent end of the tank, a hand squeegee or other device will be used to sweep the scum across the end of the tank to the skimming weirs. Scum drawn over these weirs will drain through a pipe in the effluent wall to scum ejector stations, in which are installed automatic operated pneumatic ejectors, manufactured by Yeomans Brothers, Chicago.

Two ejector stations are provided, each station serving two settling tanks, and in each station two ejectors are installed. These ejectors have each a capacity of 13 cu. ft. and are operated by compressed air. The 4-in. discharge pipe runs through the tunnel pipe gallery provided in the central wall of the settling tanks and will eventually be hooked up to the sludge disposal works.

Grit and Screening Ejectors.—The grit and screenings are brought to the ejectors on a "Sandvik" steel conveyor belt and discharged through hoppers into the ejectors. There are two ejectors, each for grit and screenings, each unit having a capacity of 15 cu. ft. The grit and screenings will temporarily be disposed of at the site by burying at a suitable place, to which the discharge piping is carried. Disposal by incineration or other methods may be adopted after sufficient operating data is obtained on this portion of the plant. The discharge piping is furnished with a swivel joint to facilitate the disposal. For this reason these ejectors were not made fully automatic.

As the ejectors fill up, a red light will indicate which one is full and at the same time an alarm will attract the operator's attention, who in turn will make the necessary arrangements at the disposal site before admitting

the air to the ejectors. The control equipment is mounted on panelboards on the screen chamber operating floor. In order to have a record of the amount of grit and screenings, each ejector is furnished with a revolution counter, which may be disengaged in case trial operations are necessary. These ejectors were furnished by the Pneumatic Ejector Company, Newark, N. J.

Pumping Equipment.—The central control station contains the miscellaneous pumping equipment, the compressed air plant and the electrical control panels.

Sludge collected in the settling tank sumps will be taken to the pumps in the main control station through an 8-inch cast iron suction line. The withdrawal of sludge from the tanks is controlled by four 8-inch motor-operated plug valves for the throttling or shutting off the flow from each of the tanks. The valves are of the Merco-Nordstrom type operated by Limitorque control. The sludge handling pumps are of the Barnes plunger type and each of the three units installed at the present time has a capacity of 150 g. p. m. Space for one future unit is reserved. The control of the rate of withdrawal of sludge from the settling tanks is of paramount importance in reducing the moisture content in the sludge as drawn, and accordingly a Reeves variable speed unit is installed as part of one of the pump drive units, and by means of this device the rate of pumping with that particular unit can be varied from 25 to 150 g. p. m. By using this specially equipped pump for minor variations in rate, and by using any designed number of units running at constant speed and discharging 150 g. p. m., any desired rate of withdrawal from the tanks can be maintained.

In addition to this control, there is installed on the force main to the sludge works a sludge sampling trough. After some experience the operator can easily judge the quality and moisture content of the sludge pumped to the sludge tanks by means of this little device, and he will also be able to control the proper pumping rate and the proper time to stop drawing sludge from the settling tanks. The sample of sludge drawn from the force main will run through the trough by gravity to a 50-gallon automatic ejector, which also serves the toilets in the pumping station. The maximum dynamic head on the sludge pumps is approximately 40 ft.

For use in dewatering settling tanks, two 3000 g. p. m. Turbine Equipment Co. horizontal centrifugal pumps are mounted in the station. The capacity of these units is adequate to dewater one settling tank in 5.8 hours. The discharge from these pumps is connected to the influent flumes at two different points, of which one is located in such a position that at times of low flow in the incoming sewer the pumps can be started and kept running for a certain period of time to help create a better velocity condition in all the various units up-stream from the settling tanks.

One 500-g. p. m. Turbine Equipment Co. horizontal pump is installed

to handle the dewatering of the grit chambers. This unit is also interconnected with the two 3000 g. p. m. pumps. This is done in order to have some means of flushing the piping in connection with the sludge works, the sludge tanks and the wet well in the sludge pumping station. In order to do so, the piping layout is so designed that the dewatering suction line from the grit chambers will be used as a force main. The valves on this line are so placed at the grit chambers that by-passing of the flow this way offers no inconvenience.

The dewatering pumps are, for ordinary operation, self-priming. At certain times, however, it may happen that a pump has to be started when the sewage level in the various units to be dewatered is low enough to require priming. To take care of this condition, there is installed in the main station a rotary single stage high vacuum Beach-Russ pump, designed for a capacity of 90 cu. ft. per minute of free air when operating against a vacuum of 15 inches of mercury. The 2-in. vacuum line connected to the various pumps has a loop above the floor high enough, with careful operation, to prevent sewage from being drawn into the vacuum pump. In case of negligence, however, this may happen, and to prevent trouble, a vacuum reservoir, that is, a cylinder tank 5 ft. high and 2 $^1/_2$ ft. in diameter, is installed next to the vacuum pump.

Piping.—Bitumastic enamel lining was adopted for the various piping used for dewatering, sludge and scum handling. It is a well-known fact that corrosion in such lines easily takes place, with a consequent increase in friction and pumping head. The result is inefficient pumping units and upsetting of the designed relation between head, discharge and efficiency. In order to be able to check the condition of the pipe lines at any time, a number of standard pitometer connections were made, both in the suction and discharge line, and the usual vacuum and pressure gages were provided for at the pumps.

As the design of the plant progressed, it became evident that some easy means of access to the various piping would be necessary. None of the major piping, except drains, were buried in concrete. Pipe galleries were provided for under the effluent wall, the influent wall and one tunnel connecting the two in the central wall of the plant. These pipe galleries are of ample dimensions, and carry the scum lines, sludge lines, dewatering lines, air lines, water mains and electric conduits. All valves on these lines are easy to reach and operate, adequate drainage is taken care of and electric outlets provided for at frequent intervals.

Another pipe gallery was carried under the grit chambers, which takes care of grit chamber dewatering lines with valves, air line, water main and the sludge force main to the sludge storage tanks.

In order to facilitate the identification of the various lines, a painting schedule of various colors was worked out. In addition to the practical

purpose of the color scheme, it lends an artistic touch to the piping layout, and makes the underground pipe galleries look more interesting and cheerful.

Compressed Air Plant.—This plant located in the main control station consists of two Ingersol Rand Class "ER-1" belt-drive, single stage, straight line air compressors, with single water jacketed compressing cylinder. Each compressor has a free air capacity of 215 cu. ft. per minute, with a final discharge pressure of 75 lb. per square inch. Each of the two units is driven by a 30 hp. ball-bearing, squirrel cage induction motor, with pulleys and slide rail base.

Compressed air must be available at the plant at all times to operate the ejectors, and for that reason the air plant is made automatic. The usual arrangement with air receivers is therefore installed, each receiver being 4 feet in diameter and 12 feet high. The receivers and compressors are inter-connected to insure an uninterrupted operation in case incidental repair or inspection of one unit is required.

In order to increase the efficiency of the air plant, considerable thought was given to air intakes. In winter the air will be brought to the compressors through an intake located on the roof of the building, where a small air filter unit is installed. By this arrangement cold, clean air is supplied. In summer, however, this set-up would be rather unsatisfactory. By valve arrangement the air can then be taken from the inside of the pumping station, where temperature at times will be at least 20° to 30° lower than outside on the roof.

Use of Everdur.—The selection of a corrosion-resistant alloy for use in special machinery or as structural members in parts of the plant where corrosion due to raw sewage would be most likely, and replacement difficult or expensive, received special attention. Everdur, which is a copper-silicon-manganese alloy, was finally selected. Because this metal can be made up in any shape or form (cast, rolled, etc.), it is adopted for use in many parts of the treatment plant. Some of the equipment and places in the plant where Everdur was used are swing gate, built up composition sluice gates, coarse bar rack apron, effluent weirs and scum weirs, structural scum baffle brackets, walkway, guides, manhole steps, anchors nuts and bolts.

While Everdur is found to be a desirable corrosion resistant alloy, it is not recommended for use in chlorine atmospheres or in direct contact with strongly chlorinated sewage.

Electrical Design.—The incoming line, 4000 volt switchboard, the main 440 volt switchboard and the 110 volt lighting distribution switch board are located in the main control station which is in the same building as the administration offices and laboratory.

From the main 440 volt switchboard, two parallel power feeders are

carried to the local 440 volt switchboard located in the screen house. Feeders are carried also to the local 440 volt switchboards located in the Venturi meter building and in the tunnels under the settling tanks.

The control of the entire electrical equipment of the plant is centralized in the main control station, that is, the administration building. Any portion or all equipment can be shut down or placed into operation from this point.

Available at the 440 volt main switchboard is remote control of such units as the settling tank dewatering pumps; grit chamber dewatering pumps; cross collectors; compressors; sludge pumps delivering to storage or digestion tanks; and motor controlled sludge valves.

A feeder from the secondary side of the lighting transformer carries electrical energy to the lighting distribution switchboard, which adjoins the main 440 volt switchboard in the control station. From this distribution center, feeders are carried to all the local lighting distribution cabinets.

Motors are all individually controlled and provision made so that any motor can be shut down locally by use of disconnecting switches located at the motor.

All equipment is thoroughly grounded with a complete system of parallel ground connected to a water pipe in each building and to four driven ground electrodes outside the buildings. Ground electrodes have been banded together with bare copper cable buried in the ground and having a penetration of 20 feet.

Structural Design.—A detailed description of the structural design of the various elements of the plant would be beyond the scope of this paper. One phase of this matter, however, namely, that pertaining to the design of the settling tanks and foundations therefor, involved unusual considerations and was of such importance that it is believed that some mention should be made of it here.

Because of the poor soil bearing capacity within the settling tank area, and the unusual conditions with respect to uplift and flotation, a number of alternate designs were investigated for the type of foundations to be selected. Five of these schemes are briefly described below:

1. All walls supported on cantilevered type footings, maximum soil pressure not to exceed 3000 lb. per sq. foot. A steel sheet piling cut-off to rock to be provided beneath each wall to retard the free passage of ground water occasioned by the underdraining of one tank during dewatering operations, while the ground water at the adjoining tank is at its normal elevation. An elaborate system of underdrains to lower ground water in order to prevent flotation of tank when dewatered. The underdrain pumps were to be controlled by the sewage level in the tank during dewatering operations.

While the construction cost of this scheme was lower than that of the others investigated, it was not accepted because (1) during excavations for the settling tanks it was discovered that this area, which was found to be the former bed of the Elizabeth River, was literally peppered with "soft spots" and that the soil bearing values assumed could not be counted on. Furthermore, the rock within this area, to which the steel sheet piling wall cut-off was to be driven, was found to be seamy, and the effective cutting off of the ground water and river flow from this area was problematical. Also the effective operation of the underdrain system upon which great dependence would be placed introduced an element of uncertainty.

2. This method was to provide a bottom slab of sufficient thickness to withstand uplift and flotation at normal tide, that is, at a tide elevation of +3.0 The important modifying principle upon which this design was based was that the settling tanks would be so operated that they would never be dewatered when the tide elevation was above +3.0. The slab thickness required in this design was 7 ft. 6 in., which carried the foundation to a point of more satisfactory bearing soil.

This scheme was not accepted because of the excessive cost, the cost being 205 per cent that of Scheme I. Furthermore, this scheme required an elaborate electrical alarm and control system to prevent dewatering of tanks at hazardous times and injected the personal element into its operation, the certainty of which cannot always be relied upon in a plant of this nature.

3. This method was an extension of Scheme II, the chief object being to eliminate the personal element and the electrical alarm and control system by increasing the slab thickness. To do this, a slab thickness of 9 ft. 6 in. was required. The cost of constructing this scheme would be 263 per cent of that under the first method. Because of the high cost, this method was not adopted.

4. This method contemplated the construction of a complete concrete cut-off to a depth of 18 inches into rock and the adoption of an arch-system of floor slab support.

While structurally, this scheme was found to be very satisfactory, the large increase in concrete yardage and special forming and excavations brought the cost to nearly three times that of the first method, and consequently eliminated this method from further consideration.

5. This method, which was finally selected, provided for a complete concrete cut-off wall to a depth of 18 inches into bed rock under each of the tank walls. In this scheme, the tank floor slab was made 18 inches thick and provided with sufficient holes to permit the relief of uplift pressure due to chance percolation of ground water into the earth beneath the slab.

The average elevation of the top of the tank slab is −7.10 while average

elevation of rock to which the concrete cut-off was carried is −22.0 or to a depth of 15 ft. below the top of the floor slab.

These wall foundations were designed as mass gravity walls below the tank slab. The walls forming the sides of the tanks were designed as cantilevered walls above the floor.

Superstructures.—The treatment plant superstructures consist of three independent buildings, *viz.* (1) main control station and administration building, (2) screen house, and (3) Venturi meter and chlorination house. The function of these buildings is as previously described and as implied in their titles.

The main building is a two-story brick and steel structure, 31 ft. wide

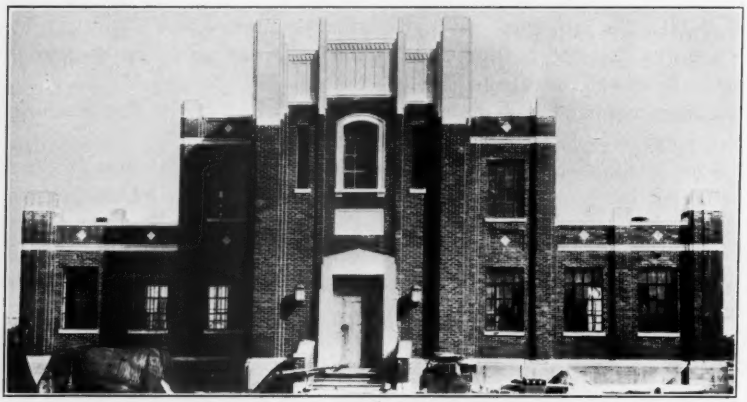

FIG. 6.—Central Control Station and Administration Building.

by 75 ft. long. (Figure 6.) The screen house is a one-story brick and steel building 39 ft. 6 in. wide by 67 ft. long. The Venturi meter house is a one-story building of similar construction, 24 ft. by 30 ft. in plan.

Face brick used in the construction of the buildings was manufactured by the Binghamton Brick Company. This brick is a rough texture having variegated colors of a full color range from highly vitrified black to crimson red. All face brick was laid with a deep tooled joint and a straight bond was used to obtain the vertical lining effect at the various columns.

Interior walls are finished in cement plaster, glazed terra-cotta and tile. Cement plaster is used generally throughout the plant excepting (1) entrance foyer of main building where glazed terra-cotta is used; (2) laboratory in main building where tile is used for wainscoting; (3) superintendent's office where wood paneling is used. The base of all walls receiving cement plaster will be finished with quarry tile.

Excepting the floors of the offices which will receive an extra finish of

cement, troweled smooth, and a linoleum cemented thereto, all floors in the buildings will receive a finish floor of terrazzo.

Interior ceilings are of the hanging type supported on straps embedded in the cinder concrete floor and roof slabs.

For heating the main building and screen house, a two-pipe gravity vapor steam system has been installed to operate on 2-lb. pressure.

Both buildings will be heated from a central boiler located in the substructure of the main control station. The system is an automatic oil burner installation; the requirements of the various buildings being served through thermostatic control of motor controlled valves on steam mains and pressure control of the Petro-Industrial oil burner.

The Venturi meter building being too far distant from the central heating plant for economical heating from that source will be independently heated by electricity, control to be automatic through a magnetic switch and thermostat to keep temperature in this building above freezing.

Stationary ventilators as manufactured by H. H. Robertson Company have been provided throughout the buildings. The screen house has been equipped with six 2 ft. by 4 ft. rectangular ventilators to provide 20 air changes per hour in this building. The chlorination section of the Venturi meter house is equipped with two 2 by 2 ft. square ventilators to provide 10 air changes per hour in this building.

Laboratory.—A laboratory fully equipped for making all necessary chemical and bacteriological tests for control of plant operation is provided on the second floor of the administration building.

The laboratory occupies a space 30 ft. long by 12 ft. wide, and is provided with terrazzo flooring and tile base. Water, gas, electric, vacuum and steam services are provided, as well as a complete list of apparatus for the above described work, together with appropriate laboratory furniture and fixtures.

Regulations Pertaining to Qualifications of Sewage Works Operators*

BY WARREN J. SCOTT

Director, Bureau of Sanitary Engineering, Connecticut State Dept. of Health

The subject of regulation of licensing of municipal, district and institutional sewage plant operators is one that has evoked much discussion by sewage plant operators and those concerned with the supervision of sewage plant operation. Any scheme of regulation or licensing should have as its fundamental objective the betterment of sewage plant operation. Tenure of office is involved but should not of itself be advanced as a basic reason for licensing or regulation of sewage plant operators. In other words, simply to insure a life-time job for a sewage plant operator is no valid reason except from his own viewpoint for any scheme of regulation or licensing, but in so far as insured tenure of office affects plant operation it is to be considered.

Almost all of the states in this country have laws which provide for some kind of state regulation for the operation of municipal sewage treatment plants. It is very logical that the state should exercise some control over disposal of sewage by municipalities inasmuch as the improper disposal of sewage in one community may harmfully affect neighboring communities. It is true that in some instances sewage discharge from municipalities in one state may affect municipalities in another state, but in these instances coöperative agreements or compacts between states serve to provide a means of handling the problem.

Usually the state supervisory agency is the state board or department of health inasmuch as the operation of practically every sewage treatment plant involves direct or indirect health considerations, whether they are pollution of water supplies, bathing beaches or shell-fish areas; nuisances as to odors; or possibilities of disease transmission by flies having access to infective sewage material.

In evolving any method of regulation or licensing of sewage plant operators there are certain relationships that must be considered: (1) the relationship of the municipality to the state; (2) the relationship of the sewage plant operator to the state; and (3) the relationship of the sewage plant operator to the municipality. The first must, of course, be of prime importance, inasmuch as the state through its administrative agencies exists to serve the municipalities as a whole.

The relationship between the sewage plant operator and the state administrative agency is usually a cordial one. There may be instances where some operators consider that state health department engineers

* *Presented at the Fall Meeting of The New York State Sewage Works Association, White Plains, October 27–28, 1933.*

think only of trying to catch them unawares, but this is unusual. The conscientious operator realizes that the intent of the state representatives is to help him with his problems in an entirely sympathetic way, and I believe it is this cordial relationship to a large extent that enlists the support of most sewage plant operators in any program for state licensing. In some cases, supervisory municipal officials with varied interests in schools, highways, parks and waterworks, as well as sewerage systems, do not extend to the sewage plant operator as much interest and support as the operator would like but he must realize that the municipal supervisory officials are the direct representatives of the people who finance the sewerage system and he must bend his efforts toward enlisting their support. Municipal officials as a whole are becoming increasingly interested in sewage treatment in accord with growth of public interest.

In most states, the law requires that plans for sewage treatment plants must be approved by state agencies, usually the state boards or departments of health and sometimes by other state boards or commissions. This is because (1) the state as a representative of neighboring communities is vitally concerned as to what type of treatment any particular municipality installs, and (2) it is possible for the state to set up technical supervisory personnel to pass on plans for sewage treatment plants which would obviously be impossible for any except large cities. Even in large cities, the technical personnel are usually actively employed on plant design so that impartial outside advice is desirable.

The state is even more vitally interested in sewage plant operation. Improperly operated municipal sewage treatment plants may harmfully affect neighboring communities. This is recognized in many states by the practice of specifying in the written approvals issued for sewage treatment plants, a provision that the operation of the plant must be satisfactory to the state department of health. This has long been the practice in Connecticut.

In the State of Ohio, such a provision is followed up by the state department of health, who insist that the municipality must provide a properly qualified sewage plant operator. It is doubtful, however, as a matter of policy as to whether this provision is specific enough. In states where such qualified statutory sewage plant approvals have not been a matter of many years standing, statutory approval was not required for old plants. It is understood that Ohio is considering the adoption of regulations as to qualifications of sewage plant operators. The State of Michigan licenses or regulates the operators of water treatment plants but not sewage treatment plants. The writer has not attempted to compile any tabulation as to statutory licensing or regulation of sewage plant operators in the various states although he is of the opinion that the number of states where specific licensing or regulation is provided for is small. However,

the recently enacted law regarding sewage plant operators in Connecticut now brings two states bordering on New York State in the class where such laws have been enacted.

In New Jersey, the State Department of Health issues licenses to operators of municipal sewage treatment plants. These licenses are issued as Grade A, Grade B, etc., depending upon the type of plant which each operator is considered qualified to handle, the size of the plant, and whether or not the plant effluent might adversely affect public water supplies or shell-fish areas. In other words, it is required that an operator of a sedimentation type of plant for a very large city have a higher grade license than the operator of a similar type of plant in a small village. Similar distinctions are made as to plants on public watersheds and near shellfish grounds and plants which are not so situated. To secure a license, the operator must pass examinations given by the New Jersey State Department of Health. Training and experience as well as the records on written and oral examinations are what count in the licensing. Each plant is required to have an operator with a certain grade license.

It has been found that short courses such as those given at Rutgers University have been very helpful in enabling operators to pass examinations such as are given in New Jersey, and due credit is allowed applicants for New Jersey licenses who have completed such a course. We have found that in the case of a new activated-sludge plant in Connecticut, where the municipality provided that the consulting engineer must break in the operator for a period of sixty days, the operator developed into a very satisfactory man. In another Connecticut town, the sanitary engineer employed by the consulting engineer as resident engineer during construction of a recently completed plant was hired as plant operator. In Ohio, it is understood that sometimes the breaking in of a new operator by the operator of a plant in a neighboring city has worked out very well.*

The Connecticut law amended by the 1933 legislature to provide for the regulation of sewage plant operators reads as follows, the underlined words being the words added to the statute by this year's action:

Section 2547 of the general statutes is amended to read as follows: "No person, corporation or municipality shall place in or permit to be placed in, or discharge or permit to flow into, any of the waters of the state, any sewage prejudicial to public health. The state department of health may investigate all points of sewage discharge and may examine all existing or proposed public sewerage systems and refuse disposal plants, and may compel their operation in a manner which shall protect the public health or may order their alteration, extension and replacement when necessary

* Many practical men, who have had no previous experience in sewage treatment, have been developed as successful sewage plant operators in Connecticut and presumably elsewhere, under the close guidance of sanitary engineers of the state department of health.

for the protection of public health and the qualifications of the operators of sewage treatment plants shall be subject to the approval of the state department of health. No public sewerage system or refuse disposal plant shall be built until the plan or design of the same shall have been filed with the state department of health and approved by said department, and no such system or plant shall be built, extended or replaced, the effluent or discharge from which may or shall directly or indirectly mingle or come in contact with the waters of the state until the plan for the same shall have been approved by the state water commission under the provisions of chapter 142 of the general statutes."

Following out the intent of this law, the Public Health Council of the Connecticut State Department of Health on August 28, 1933, adopted regulations governing the qualifications of operators of sewage treatment plants. These regulations are stated below.

Rules and Regulations Concerning Qualifications of Operators of Sewage Treatment Plants

(*a*) The term "operator" shall apply to any person who shall have active field supervision of a sewage treatment plant. It shall not apply to a city engineer, public works superintendent or other similar official who exercises only general supervision. There shall be at least one operator in charge of every sewage treatment plant operated by a state institution, city, town, borough or other municipal district or sub-division, or by any person, firm, institution or corporation providing sewerage facilities for 1000 or more persons, or for lesser numbers when necessary in the opinion of the state department of health.

(*b*) Each operator must be in good physical condition so as to enable him to perform necessary manual labor at his plant.

(*c*) Each operator must submit evidence satisfactory to the state department of health that he is qualified: to read typed instructions furnished him by the state department of health; to keep necessary written records required by the state department of health; to operate various valves which direct sewage to different units of the plant; to operate sludge drawn-off mechanisms; to clean and properly care for sludge drying beds and/or intermittent sand filters; to operate and make the simple tests required to keep chlorinating equipment, where supplied, in efficient operation or to make other simple necessary field chemical tests where necessary; to be sufficiently familiar with the end to be accomplished in the plant processes so as to recognize faulty operating conditions and if such conditions exist, to overcome them if practicable.

(*d*) Each operator of a plant employing machinery such as pumps,

engines, electric motors, air blowers, etc., must submit evidence satisfactory to the state department of health, of previous mechanical training and experience, which shall be sufficient to enable him to properly care for and carry out minor repairs on mechanical equipment at the plant, and he shall have a general knowledge of the principles involved in the operation of the particular equipment for which he is responsible.

(*e*) Operators of plants employing activated-sludge treatment or other processes involving a highly specialized knowledge of physics, chemistry or bacteriology must submit evidence satisfactory to the state department of health, of sufficient technical or specialized training along lines such as to qualify the operator to secure satisfactory operating results from a particular plant. Where a knowledge of laboratory technique is needed, the operator's qualifications shall meet the approval of the state department of health.

(*f*) Confirming and supplementing the above requirements, each operator shall possess a sufficient degree of application, initiative and judgment so as to enable him in practice to secure plant operating results satisfactory to the state department of health.

These regulations were given considerable publicity through the department weekly bulletin and the newspapers. Copies were forwarded to municipal officials in the various municipalities by the commissioner of health with an accompanying letter, explaining the attitude of the department. In this letter, the commissioner stated that the department did not intend to give examinations to the present operators of sewage plants nor to take action toward disturbance of any of the present plant operators unless necessitated by unsatisfactory plant operation. The department to date has made no requests for changes although a request for replacement of one plant operator is now under advisement. It appears probable that the municipality itself may shortly replace this particular operator, however, without necessitating any action by the department. We believe that as a whole we have a very good set of sewage plant operators in Connecticut. Obviously, in the case of future new plants or replacements of plant operators, the department will require that new operators possess suitable qualifications before assuming charge.

To return to the New Jersey and Connecticut requirements as to qualifications of sewage plant operators, there is, of course, one basic difference. The New Jersey law provides for licensing and this, of itself, tends to make the operator definitely responsible to the state. It probably is more effective than our Connecticut set-up in insuring tenure of office for operators. The New Jersey State law, when passed, contained a clause providing that all persons operating sewage treatment plants at the time of passage of the act must be granted state licenses upon application of the municipality, without examination. In New Jersey, so far as the writer

is aware, no municipality may replace the operator of a sewage treatment plant except from a list of licensed operators of the proper grade. In Connecticut, there is nothing in the law which prevents any municipality from making a change in the operator of a sewage treatment plant provided a capable man is put in his place who will meet the requirements of the state department of health. There is, of course, always the possibility of objections being raised to the passage of a law which contains any provision that would take away from any municipality the right to choose its own employees, assuming they are capable.

In the states where there are Civil Service laws, sewage plant operators might be placed under Civil Service requirements. There would need to be close coöperation between the state department or board of health and the Civil Service Commission under such circumstances to secure satisfactory working results.

Despite the fact that politics frequently enter into the selection and replacement of sewage plant operators in cities, sometimes to the extent of working rank injustice upon capable operators, it seems doubtful if this fault of municipal set-up justifies an attempt by the state to enter into the control of local governments. The state's duties appear to end in raising the standards for sewage plant operators to a point where satisfactory operation is assured. Looking at the matter, too, from a practical standpoint, satisfactory operation of a municipal sewage treatment plant rests not only on the provision of a capable operator but also on the financial and other assistance which the operator must secure from the local government. An operator entirely out of tune with his local government is not likely to get very far with his plant.

The state can help in attaining efficient sewage plant operation by setting up satisfactory standards for sewage plant operators but operators must not assume that the state can or should take over the whole matter of hiring and firing of sewage plant operators. The operator in his own community can do a great deal to strengthen his position and enhance his value to the community by getting the most out of his plant by careful attention to plant operation, and by enlarging his knowledge of the art of sewage treatment through observations of operation of his own and other sewage treatment plants, through studies of text-books and journals dealing with sewage treatment and through attendance at schools and conferences on sewage treatment.

Discussion

BY F. D. STEWART

Principal Assistant Engineer, Ohio Department of Health

Licensing of sewage plant operators appears to be a much discussed topic of conversation at this time, particularly among gatherings of plant

operators. The primary object of the movement is, or should be, to secure or guarantee the continuous efficient functioning of sewage plants, and consequently state health departments are intimately associated with any plan proposed. We have been asked to discuss control of sewage plant operation in Ohio from the standpoint of the Ohio Department of Health.

There are no statutes in Ohio requiring operators of sewage plants to be licensed, nor has there been any serious contemplation of attempting to promulgate any, although there has been a report of licensing as it existed in other states at our 1932 conference on sewage treatment. We do have a basic statute which gives the department of health rather broad powers pertinent to sewage plant management. Being rather short it is included herein:

"Sec. 1240-2. (State department of health shall exercise general supervision of the disposal of sewage and industrial wastes.) The state department of health shall exercise general supervision of the disposal of sewage and industrial wastes and the operation and maintenance of works or means installed for the collection, treatment or disposal of sewage and industrial wastes. Such general supervision shall apply to all features of construction, operation and maintenance of such works or means which do or may affect the proper treatment or disposal of such sewage and industrial wastes. For the purpose of exercising such general supervision the state department of health shall investigate the works or means employed in the collection, treatment and disposal of sewage and industrial wastes whenever deemed necessary by the department and whenever requested to do so by local health officials; and may adopt and enforce orders and regulations governing the operation and maintenance of such works or means and may require the submission of records and data of construction, operation and maintenance, including plans and descriptions of existing works or means of disposal of such sewage or wastes. When the state department of health shall require the submission of such records or information the public officials or person, firm or corporation having the works in charge shall promptly comply with such order. (111 v.25.)"

In addition to the foregoing, we impose administrative control, particularly with the larger plants, by stipulating, when approving plans for a large plant, that expert technical superintendence shall be provided for the operation of the proposed plant. By and large it is fair to state that our plants serving cities over 10,000 population are operated by men with technical ability.

As is no doubt the case in all states, our problem has been, and still is, the securing of some technical control of operation of the many small plants throughout the state. Here we have copied the plan initiated some fifteen years ago with small municipalities having water purification plants,

which is to have the small town retain as technical supervisor for its plant the superintendent of a nearby city plant. The supervisor may make one, two, four or more visits per month, depending upon the requirements. He is the school teacher of the local operator, so to speak, and in addition is held responsible for the successful functioning of the plant. He also makes the analyses incident to the operation, usually in the number of his visits, except for such routine simple analyses which he feels may be left to the local non-technical operator.

The charges for service of this kind vary from $25 to $100 per month, depending upon the frequency of the visit. The amount of visitation should be and usually is determined by a general agreement between the state department and the municipality, but too often it is the amount the town feels it can pay, particularly during these times of financial difficulties. Where a town raises funds by sewer rental the problem is simplified and no trouble is experienced. As a matter of fact, we find it relatively simple to persuade our smaller cities to employ full time technical operators when sewer rental is practiced, as the smallest practical charge will insure sufficient funds for this purpose.

Probably another reason for licensing of operators is to insure the continuance in office of present incumbents; or, in other words, to prevent changes in personnel due to political changes in city administration. There is grave reason to doubt that this will be accomplished. In our state, where political turn-overs are frequent, no great amount of trouble has been experienced, as the technical men as a rule endeavor to divorce themselves from politics. When a change is insisted upon by city officials, no rules, civil service nor licensing can prevent them from accomplishing their purpose. When this occurs our policy is to insist that the new man for the position be qualified by technical training and experience to superintend the specific plant in question.

An interesting situation arose recently which illustrates what may occur in this regard. A plant comprising sedimentation and trickling filters, and modern in every respect, was completed and a competent technical man put in charge of operation. It shortly developed that he was employed for only a short period, to tune up the plant, and that another man, adequately trained in recreation and playground supervision, was slated for the position, and no arguments against this change would seem to prevail. Fortunately, the civil service commission of the city stepped in and held an examination, as required by the act of the city council in establishing the position. A well qualified man is now in charge of the plant.

Discussion

BY E. B. BESSELIEVRE

The Dorr Company, New York City

The benefits of licensing sewage works operators more than counterbalance the disadvantages that have been advanced. It has been said that licensing removes the operator from the jurisdiction of the city which employs him. This is not necessarily so, and depends entirely upon regulations surrounding the law of enforcement. Licensing an operator of a plant is a guarantee that the man charged with the control of a system of biological processes and mechanical operations knows what it is all about. Tenure of office is not guaranteed any more than the possession of a college diploma or the certificate of one of the major engineering societies guarantees any engineer that his job is secure.

Licensing protects the city which invests money in a sewage plant, both in assuring full value for that money in operation which assures the production of an effluent satisfactory to the state; it assures the state that they will get records of operation which are trustworthy and correct, and it removes the plant from political mishandling. These certainly are benefits.

Granting a license to the operators who were employed before the license law is invoked is not a good policy. Such men, to retain their positions, especially if the plant has been remodeled, modernized or changed materially, should be made to conform to the same rules and regulations as new applicants. Where the operators can show that they have attained the degree of efficiency necessary to obtain a license they may be given certificates.

A license, like a diploma, is not a guarantee that the holder has a given degree of knowledge, but it does certify that he has satisfied those in authority that he has been trained along lines which should normally assure a degree of efficiency in that profession or trade.

Many grades of license are not required. Three, or even two, grades would seem to cover most cases. The operator should be examined on the processes, methods and units contained in the plant he is to operate, not on a nebulous, hypothetical plant which he may never use. The average operator is not an itinerant and is usually selected by the engineer of the city before a given plant is completed, and is put on a definite plant, and normally operates it for periods of years.

Designing engineers of plants, particularly those developing systems which are more complex than some of the older types, should have as a requirement of their contract that they select or recommend a man as an operator, instruct and train him in the principles of design of the plant,

its scheme of operation and the results to be expected. This supervisory period should continue for at least one year after initial operation.

Licensing of operators, properly controlled, should assist any state department of health to maintain the sewage plants under its jurisdiction in better general condition with the least inspection. Short schools are of material benefit in training existing and potential operators.

Mr. Scott has pointed out the requirement for physical fitness of operators. I believe this a necessary rule, as I have seen several cases where men, politically selected, too old and feeble to get around, have been placed in charge of modern sewage plants. In one case a man of this type, crippled, was found lying outside the door of the plant unable to rise and enter the door. Obviously, he was not the proper type to control that plant, which required that he climb several ladders to reach valves and other units.

I believe that an operator who has been awarded the certificate of license is proud of that fact and will usually hang it in a conspicuous place, so that all who run may read that he has met the test and stands approved.

Control of Odors from Grease Skimmings by Chlorination at Erie, Pennsylvania*

BY A. B. CAMERON

Superintendent of Sewage Treatment Works, Erie, Pa.

The Erie sewage treatment plant is one of the larger, modern treatment plants in the country. The plant is of the separate sludge digestion type, providing only primary treatment. For details of design, the reader is referred to a paper by the author published in THIS JOURNAL, Volume IV, p. 800, Sept., 1932.

Sedimentation is effected by two 90-foot Dorr traction clarifiers, operated in parallel. Each of these clarifiers is equipped with a mechanical skimmer which effectively removes the grease, scum and miscellaneous debris from the surface of the tanks.

As the mechanism revolves, the grease and other floating materials are collected from the surface of the tank and concentrated at one corner, immediately adjacent to a sump. At a definite point in the revolution of the clarifier mechanism, a valve located between the clarifier proper and this sump is tripped, thus allowing the accumulated material to flow from the surface of the tank into the sump. Operating at the same time and synchronized with the opening of the valve is a secondary skimming arm which assists in forcing the collected material into the sump.

Each sump is approximately 4 ft. square and 6 ft. deep. A screen having 1-in. square openings is installed in each sump to collect sticks, rags, etc., which might clog the pipe lines. These screens are cleaned periodically by shoveling the collected material into garbage cans. Ultimate disposal of this material is by incineration.

The screened liquor, containing the grease, scum and other finely divided floating material, flows about 200 ft. through a 6-in. cast-iron pipe line to a concentrating tank located in the incinerator building.

This tank is 16 ft. square by 6 ft. deep at the flow line, and is equipped with an inner baffle extending $2^1/_2$ ft. below the flow line. The influent line from the sumps enters this tank at the center and discharges $2^1/_4$ ft. from the bottom of the tank. The tank is equipped with suitable drains and flushing facilities.

As the liquor from the sumps enters this tank, the grease and lighter materials rise to the surface, from which they are removed by hand-skimming into garbage cans for final disposal by incineration or burial. The comparatively clean sewage effluent rises between the inner baffle and the overflow weir where it is collected and recirculated through the plant.

* *Presented before the Seventh Annual Conference of the Pennsylvania Sewage Works Conference at State College, Pa., September 6, 1933.*

The writer is of the opinion that decomposing skimmings produce some of the most foul and obnoxious odors that are encountered about a treatment plant. In the case at hand these odors were confined to one building, but conditions in this building were very bad indeed. Frequent skimming and a blower system effected some improvement, but after a few months of operation it became apparent that some rather drastic remedy would have to be found if this part of the plant was to be made as free from odors as desired. Several deodorants were tried but these did not eliminate the odor. Their action, seemingly, was to substitute a more pleasant odor for the one prevailing; also the cost of treatment was high and the means of applying the same were inconvenient and costly. The next treatment tried was H. T. H., as manufactured and supplied by the Mathieson Alkali Company, who kindly shipped us a small amount of the material for experimental purposes. A couple of tests with this material effected a decided improvement.

As most odors about a sewage plant are the by-products of bacterial decomposition, the theory was advanced that if the contents of the grease concentrating tank could be kept sterile, there would be a good possibility that odors could be eliminated at their source.

This theory was discussed with representatives of the Wallace & Tiernan Company, and while they could not guarantee results nor offer an estimate of the amount of chlorine required, they felt that the idea had considerable merit. As a result of these negotiations, Wallace & Tiernan kindly agreed to loan the city of Erie a rebuilt chlorinator to use until some definite information could be obtained as to the value of the proposed treatment. Accordingly, Wallace & Tiernan shipped the city a chlorinator which was installed and placed in service October 21, 1932. This chlorinator has been in service continuously, with the exception of a month and a half during 1932 when the plant was by-passed in order to make certain changes in the screen chamber.

As the flow to the concentrating tank is not constant but comes in "slugs," it was considered inadvisable to introduce the chlorine solution directly into the influent line due to danger of destroying the pipe work and valves.

The chlorine solution is introduced into the tank at the discharge end of the influent line, thus insuring a good mix, also, as this point is several feet below the flow line, all piping is concealed which adds neatness to the appearance of the installation.

From this tabulation several conclusions may be drawn:

1. Chlorination of this grease concentrating tank has completely solved the odor problem.

2. Cost of treatment is very nominal as an average of only 1.5 pounds of chlorine per day was used, costing about eleven cents.

3. For complete success a fairly heavy residual chlorine must be carried, the average being 1.4 p. p. m.

4. Varying quantities of grease and scum do not seem to cause any variation in the amounts of chlorine required.

5. Temperature of liquor, as was expected, apparently is the controlling factor in amounts of chlorine required.

The operating data were as follows:

OPERATING DATA ON CHLORINATION, DAILY AVERAGES

Month	Flow Treated, Gal.	Temp. of Liquor, °F.	Skimmings, Cu. Ft.	Chlorine Applied, Lb.	Chlorine Applied, P. p. m.	Chlorine Residual, P. p. m.	Remarks
1932							
Oct.	5000	67	7.2	2.3	53	...	Slight chlorine odor in liquor
Nov.							Room free from odor
Dec.	5000	54	4.4	1.5	36	1.4	Room and liquor free from odor
1933							
Jan.	5000	54	3.8	1.0	24	1.0	Room and liquor free from odor
Feb.	5000	52	7.3	1.1	26	1.0	Room and liquor free from odor
Mar.	5000	50	9.0	1.1	27	1.3	Room and liquor free from odor
Apr.	5000	54	10.8	1.3	32	1.9	Room and liquor free from odor
May	5000	58	9.2	1.6	41	2.3	Room and liquor free from odor
June	5000	65	8.7	1.7	44	1.3	Room and liquor free from odor
July	5000	69	11.0	2.3	56	1.2	Room and liquor free from odor
Avg.	5000	58	7.9	1.5	37	1.4	
Max.	5000	69	11.0	2.3	56	2.3	
Min.	5000	50	3.8	1.0	24	1.0	

Conclusion

As a result of the above experiment, the city of Erie purchased a M. S. P. type chlorinator. This machine is installed and chlorination of the grease concentrating tank will, in the future, be a regular part of the treatment.

Apparently a new application for the operator's friend, chlorine, has been found and it is hoped this will prove of assistance to other operators with similar difficulties.

Since chlorination has been adopted, this part of the plant is thrown open to visitors, whereas prior to chlorination this room was generally shunned and kept closed.

The writer wishes to acknowledge the assistance rendered by The Mathieson Alkali Company in the original donation of H. T. H. and the splendid assistance and coöperation given by Wallace & Tiernan Company and members of their staff.

Trouble Prevention in the Design of the Meadville Sewage Treatment Plant*

BY ROY L. PHILLIPS

City Engineer, Meadville, Pa.

The title "Trouble Hour" gives a sewage plant man plenty to talk about.

As the best way to handle trouble is to prevent it, the writer has taken the liberty of presenting a few novel devices, and some which are quite conventional, that have been incorporated in the design and construction of a new sewage treatment plant at Meadville.

The Meadville plant serves a population of approximately 18,000 people and requires the continuous pumping of the entire sewage flow to the plant. The pumping station and plant proper are isolated, one from the other, and a fully automatic pumping station, using four Fairbanks-Morse vertical trash pumps, 2 two-speed motors and 2 variable-speed motors with float control provide 13 different pumping capacities.

The treatment plant is located in the center of a 20-acre piece of ground belonging to the city. The equipment consists of two Link-Belt settling tanks, separate sludge digestion tanks with floating covers and gas collection, covered sludge beds, and pre-chlorination or disinfection with HTH as the equipment in the chlorine control room includes a lime feed machine as well as a chlorinator, coupled to give sufficient flexibility so that this type of treatment may be available. The effluent is discharged into French Creek. The first provision against trouble was an adequate, well located site.

The treatment plant and an adequate area immediately adjacent have been enclosed by a galvanized chain link fence and consequently unwelcome visitors and meddlers are easily excluded from the grounds. This is quite necessary as an operator is present at the plant only during the day and no watchman is employed at night. An effort has been made to provide adequate illumination at all working points on the grounds, as well as in the buildings, so that emergencies occurring at night may be met with a minimum of difficulty.

A 6-in. city water line has been laid to the plant providing 54° F. water at 120 lb. pressure and a standard fire hydrant has been installed within 100 ft. of the control building. Adequate water connections and hose have been provided at numerous points around the plant, including two outlets on the settling tanks, so that the operator may be encouraged to keep the plant clean and thus avoid trouble which is inevitable with a dirty

* *Presented before the Seventh Annual Conference of the Pennsylvania Sewage Works Association, State College, Pa., September 6, 1933.*

plant. In several cases this hose is $1^1/_4$-in. in size and provides a stream which is adequate for almost any job. As mentioned above, pre-chlorination of the sewage before it enters the settling tanks has eliminated any tendency toward odor from these tanks.

The high steep slopes around the circular digesters, on which it is very difficult to maintain proper sod, have been planted with ground covering, such as ivy, myrtle, honeysuckle, pacysandra, creeping roses, etc. This same treatment has been given to slopes around manholes, entrance drives and, in addition to eliminating the conventional difficulties with these slopes, already presents an attractive appearance.

In addition to removable slat covers over the influent channels in the settling tanks, from which point stranded materials may be removed from these channels in the conventional manner, a perforated air line has been placed in the channel bottom and supplied with air under about one pound pressure from a small Roots-Connersville blower located in the control building. Starting this blower for a few minutes several times a day is very effective in keeping the influent channel clean.

Two sludge pumps have been installed in the basement of the control building. One of these is a Barnes duplex piston pump as sold by the Dorr Company and the other is a Fairbanks-Morse centrifugal pump directly connected to a 4-speed motor. The low speed on this centrifugal is used as a standby for the Barnes in the pumping of raw sludge. The high speed is used for emergency dewatering of the settling tanks or in any similar operation where larger capacity is desired. The intermittent speeds are very useful in various operations, such as remixing, etc. This centrifugal pump is particularly valuable in connection with the use of a concentration tank which has been installed in the control building. This is a covered cylindrical steel tank with conical bottom having a capacity of perhaps 50 per cent more than one day's accumulation of fresh sludge. This tank has proved to be one of the most useful parts of the plant. It is equipped with a series of valves from the bottom to top of the tank set on 9-in. spacings so that liquid can be decanted from the tank at any level.

The plant was placed in operation without the use of any seeding material and lime was applied to the fresh sludge through the concentration tank and mixed by recirculating from bottom to top. This tank has been used for measurement, by positive displacement, of quantities of fresh sludge pumped each day; also for the concentration of this sludge by the decanting of surplus water; and has also proved very useful in handling a supernatant which, due perhaps to heavy gasification, did not readily clear up in the digesters. This supernatant was pumped to the concentration tank where the partly digested sludge settled very rapidly, giving a clear supernatant which was run into the settling tanks and the settled sludge pumped back into the digesters. Both pumps used on sludge work are push-button con-

trolled from the top of this concentration tank, from the front and rear doors of the control building, and in the basement where the pumps are located. A white enameled, supernatant inspection sink is placed in a well lighted spot in the floor near the concentration tank and a bypass line run to this sink from the supernatant line leading from the digesters and the concentrator. This eliminates a lot of the conventional difficulty of trying to see supernatant down in some deep, poorly illuminated manhole.

Gas is collected in the conventional way at the floating covers in the digesters, piped through Pacific Flush-Tank flame traps, gas meters, etc., to a common gas header. As Meadville lies in a territory where natural gas can be obtained at a reasonable price, provision is made through the installation of a natural gas service line to the plant for the admission of natural gas to the gas header, and by proper valving either natural gas or sludge gas can be used in either the B-Line Boiler for tank temperature control or in the boiler connected with the low pressure steam heating system for the control building. All pilots are on the natural gas line as a safety measure. We have already had occasion to see the wisdom of this installation. Excess sludge gas is wasted through the roof of the control building and the waste pipe has been carried well above the comb of the roof to avoid down-drafts with their attendant dangers.

An indicating and recording flow of the Venturi tube type and recording thermometers on the hot water lines to the digesters, as well as recording thermometers giving sludge temperatures, have been mounted on the main floor of the control building opposite the main entrance door and the operator has been equipped with a portable indicating thermometer with 20 feet of flexible tubing so temperatures may readily be taken at different depths. Many valves have been placed in manholes or collected in an underground room where they are readily accessible for inspection and repair. All electrical control switches for everything at the plant have been placed on one enclosed panel in the control building and push button controls used freely at different points.

Sludge pumps, hot water pumps, heating boilers and gas meters have been placed in the water-tight basement of the control building and a color scheme has been adopted for various types of piping and equipment throughout the plant so that various lines may be readily identified. A large piping plan of the plant has been drawn, framed under glass, and hung in the combined laboratory and office. The same color scheme has been used in the piping plan that is used on the actual painting of the lines themselves.

Every effort has been made to anticipate trouble and full recognition has been given to the fact that an attractive plant, one of which an operator can be proud, is the surest way to guarantee sufficient interest to avoid

many careless and lazy habits which are so often the real source of the troubles we talk about. When you find an operator on the job holidays, evenings, etc., on his own time, polishing up this or that portion of the plant, you may feel sure you have been successful in creating this desire. We have had this experience.

Operating Difficulties in a Sewage Treatment Plant*

BY FRANK B. ALTEMUS

Norristown Sewage Treatment Works

The five million gallon primary sewage treatment plant of the Borough of Norristown, Montgomery County, Pennsylvania, is now in operation. This plant was designed by Remington, Vosbury and Goff, constructed by Seeds and Durham, and mechanical equipment supplied by the Roberts Filter Company.

Our first trouble started as soon as the plant began operating. The grit chamber, despite removal of grit, became clogged. Investigation showed that considerable screenings were accumulating at the base or footing of the piping used to eject grit from chamber. This was changed to avoid recurrence of trouble. In the original design the installation of a water jet ring, consisting of a circular $2^1/_2$-in. galvanized pipe, was provided to break up grit that would pack hard on the bottom of the grit well. This ring was changed to a fishtail arrangement, which operates satisfactorily. The grit chamber is circular in design with a conical bottom, permitting a tangential flow. A $7^1/_2$ hp. motor drives the air compressor, which in turn supplies the air necessary to lift the grit from the bottom of chamber to a dome arrangement at the top of the grit chamber. The grit then flows to the grit washer and dewatering screw. While on the subject of grit, the odor given off from our grit took on the aroma of "Ye Olde Fish Market." It was discovered that the volatile content of the grit was approximately 43 per cent. The grit washer was re-designed with sluices and weirs, resulting in only 8 per cent volatile matter in the grit. The odor of H_2S has caused some very unfavorable comments by prominent engineers. As a matter of fact, one very prominent engineer is on record as having said he visited our grit and screenings chamber, and then was unable to escort his family to a movie. If this engineer were to revisit our plant, he would find a fine, new ventilating system which cost the Borough of Norristown $1500, but is certainly worth the money.

Considerable difficulty was encountered in the operation of our non-clogging sludge pumps. The immediate cause was clogging. In order to eliminate this condition, it became necessary to raise the wetted level of the bar screen, and thereby remove the screenings at that point, instead of at the sludge pumps. The results obtained can be gathered from the following figures: Screenings collected before installation of baffles back of bar screen, 10.2 cu. ft. *per week;* screenings collected after installation of baffles, 8.2 cu. ft. *per day.*

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The pumping capacity of the station is rated at 7000 g. p. m. or say ten million gallons per day. This is split up into 4 pumping units: two variable-speed units of 2100 g. p. m. each, and two constant speed units of 1400 g. p. m. capacity each. The original idea was to take care of seven million gallons peak load and a daily average of five million gallons. This would involve one unit of 2100 g. p. m. capacity, and two 1400 g. p. m. units. The fourth unit is reserved for maintenance work on any of the other operating units. However, when we experience a storm in Norristown, it is necessary to use all four pumps, valve down on the main 30-inch sluice valve, and pray to Allah that the oars are where we left them. This trouble is partially due to roof drainage and infiltration. The actual deluge starts at our normal top load of a four million gallon rate and gets up to an eight million gallon rate in slightly less than 10 minutes. We do have a 12-inch relief line that could be operated under normal conditions, but because this line opens into a flashily rising creek, it is impossible to use it when a heavy rain is experienced.

The separate sludge-digestion tanks are designed to permit the heating of tanks and gas collection. The heating arrangement consists of a series of coils, bracket mounted, and a single pipe return system. Some difficulty was experienced with the original brackets, but after a redesign of brackets and a complete new installation in each tank, the heating coils have remained stationary.

The gas collection has met with partial success—partial, in respect that it is not possible to pump sludge into a digestion tank and maintain a gas pressure that will insure the operation of gas boilers or maintain the storage of gas in the tank. This condition is caused by the pumped sludge entering the gas compartment under pressure. When the pressure is released or the pump has stopped, it is impossible to close valves fast enough to prevent the gas from escaping. On the other hand, if the decanting does not equal the pumping rate, the gas domes or seals perform their duty, and eject oil over the outside top of the digestion tanks. Several plans are being considered to eliminate this condition, which, if successful, will permit collection of gas without the aforementioned troubles.

Discussion

Mr. H. M. Freeburn, Philadelphia: Mr. Altemus is rather modest. He has had a unique experience lately in coming out of the plant at 2 o'clock in the morning in a boat. Ask him how it happened.

Mr. F. B. Altemus: What really occurred was this: We had 3 days and three nights of rain—a continual downpour—and the river started to rise about 7:30 in the evening and at about 2:30 in the morning the water reached our flood level of 63 feet. The normal water line is 42 feet and the water jumped 21 feet due to the continuous rain and probably

came up about 11 feet between 7:30 and 2:30. In our little neighborhood of Shantytown they were taking them out in boats. We were at a higher elevation but we put in a bid for a boat and paid $1.00 as a retainer. We had often felt like putting in a requisition for a row boat before and we really needed one. Our walls started to sweat from the pressure. The water came in and with no way to stop it. The superstructure leaked and about 2:30 the place was flooded. After the flood was over it took about 26 hours pumping to clear out the water. We had about $500 damage.

Mr. H. E. Moses, Harrisburg: There was another plant at York from which the operators went out in a hurry.

Mr. M. B. Tark, Philadelphia: The York plant is surrounded by a dike and the water was 2 feet above the dike. The pumping station was completely drowned out.

Mr. L. H. Enslow, New York City: Tell us about the baffles.

Mr. F. B. Altemus: These baffles were a series of boxes of cypress boards arranged with a slotted effect in the middle. They retard the velocity of approach to the bar screen. This baffle arrangement is put in back of the bar screen and something like 2 boxes not quite coming together, with a 4-inch slot between. They are 24 inches in height and the sewage flows over them and they act as a baffle. We had a slight backing up and settling, but not much static head.

Sludge Problems at State College*

BY RALPH R. CLELAND

Sanitary Engineer, The Pennsylvania State College

The solid content of sewage is approximately 0.1 per cent of its total volume, the remaining 99.9 per cent being water. In the operation of a plant treating sewage it happens that 99.9 per cent of the troubles encountered are those caused by a part of the 0.1 per cent known as the sludge. At least such is the case at State College. With Imhoff tanks supplying a sludge digestion volume of 1 cubic foot per capita, a figure inadequate for our conditions, the sludge remains in the tanks for an average of 50 days, which time is insufficient to digest it. The troubles of an overloaded tank then follow, namely, contamination of the flowing-through chambers with solids, many of which are continuously passed onto the trickling filter; foaming and excessive scum formation because of an improper ratio of digested to incoming solids; and sludge drying problems caused by an incompletely digested sludge.

There are two well-known remedies for an overloaded tank—the first is to draw sludge and the second is to add lime. The former of these has been our only solution and the reason for its effectiveness needs no explanation—it simply makes more room for the incoming solids. The latter method, namely, liming, has been of little use to us because the benefits derived from its use were far outweighed by the cost of the lime used.

When lime is added to an Imhoff tank it is supposed to aid digestion by neutralizing acid materials; stimulate the growth of organisms responsible for the digestion of nitrogenous substances; cause the flocculation and precipitation of acid colloidal materials, particularly in the scum; and allow the gas bubbles held in the scum to escape, probably because of the changes in surface tension that take place. It has been stated by Rudolfs and other investigators that lime materially reduces the digestion period at practically all temperatures.

We have long since given up the idea of maintaining a pH of 7.0 to 7.3 in our Imhoff tanks. Sufficient lime, however, is added to maintain the pH of the liquor in the sludge digestion compartment at 6.7 at which figure we seem to control scum formation and foaming. To do this requires an addition of ground lump lime, with a calcium oxide content of 98 per cent, amounting to 203 pounds per million gallons of sewage treated, or approximately 55 pounds per thousand gallons of raw sludge. Our raw sludge runs 5 per cent in solids, of which 15 per cent is ash, while that drawn from

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the tanks also has a solid content of 5 per cent, of which 36 per cent is ash. In other words, we effect a reduction of volatile matter of 68 per cent. The fact that the sludge is not completely digested can be demonstrated by taking samples of the sludge as drawn, placing it under tank pressure and allowing it to remain for 45 days at room temperature during which time the ash content will increase to more than 50 per cent. This has been done in the plant laboratory.

To return to liming, an experiment was conducted over a 10 months period to determine the effectiveness of lime in our tanks. During this time, one tank was limed quite heavily while the other was given sufficient to keep the pH above the 6.2. Samples of the sludge were analyzed at each removal and a composite made for a mineral analysis of the ash. From the results obtained the following facts were observed: the thickness of scum on the limed tank was 2 feet less than on the other, showing a beneficial effect in scum control; there was no difference in the drying qualities of the 2 sludges as drawn onto the beds; on analysis it was found that the pH of the sludge receiving the lime was 6.7 as compared to 6.5 for the other. The solid and ash contents of the sludge in the limed tank were of course higher with 4.93 per cent solids and 39.3 per cent ash as compared to 3.52 per cent solids and 32.4 per cent ash in the other. However, when a mineral analysis was run on the ash it was found that the increased ash content was entirely due to the lime added and that we were mistaken in thinking the higher solid and ash contents meant better digestion.

Not only does the sludge present problems when in the tanks, but it also causes difficulties when drawn onto the beds. Two years ago we began to have trouble in dewatering our sludge. There was no appreciable difference in the physical and chemical analyses of the sludge from those of the sludge which had been drawn previously and the trouble seemed to be of a periodic nature. At times it was necessary to use a centrifugal pump to remove sludge which had been on the beds for 3 or 4 weeks without draining. During this time there appeared to be a separation with a layer of sludge on the sand and one on the surface, with the intermediate 7 or 8 inches composed of clear water. From that time to the present date, alum has been used with the sludge at a rate of 2 pounds per cubic yard and the trouble has not recurred.

We are at present using crushed anthracite on one of our open beds and plan to place it on one of the covered beds for the purpose of determining the comparative efficiencies of sand and anthracite. To date, 5 runs have been made and the coal gives quicker dewatering than does the sand, while giving as satisfactory an effluent. The coal has an effective size of 0.37 mm. and a uniformity coefficient of 2.89 while the same figures for the sand are 0.26 mm. and 2.00. The void space of the coal is 40.5 per

cent while that for the sand is 37.5 per cent, thus accounting for the difference in the rate of filtration. Both materials are priced the same per unit of volume with the coal weighing approximately 55 pounds per cubic foot as compared to 100 pounds per cubic foot for the sand.

Discussion

Mr. C. L. Siebert, Harrisburg: Is the use of coal at the State College plant part of the experimentation of the Anthracite Institute?

Mr. Cleland: Partly and partly experimentation by the College. We can buy coal as cheap as sand, for the same volume of coal.

Mr. Siebert: Any particular kind of coal?

Mr. Cleland: Anthracite.

Mr. H. G. Turner: During the last two years we have been experimenting with anthracite and making considerable study of the chemical action. We find that coal has been used in various parts of the country. We have many kinds of coal from bituminous up to anthracite and super-anthracite. We find different anthracites vary in physical quality. We must have anthracite that does not have a great percentage of flat material, we must have material that is fairly angular. English so-called anthracite is not like American anthracite. The angular grain has more surface than the round grain. Furthermore, we found that the lighter weight material would not pack so tightly as the heavier—spaces were more likely to be kept open—and it occurred to us that this might be an advantage. Mr. Cleland was interested enough to try to find out and it seems to be working very nicely.

Mr. Cleland: I mention two things in which we are interested; one is how the material packs and the other, how much anthracite it will take to replace a bed as compared with sand.

Mr. Agar said that he was in favor of using lime in powdered form. We did that for some time and when cleaning the tank we found 50 per cent of the material removed was composed of lime. There were piles of lime coated with sludge and the lime itself could not get into the solution. What advantage has powdered lime over liquid?

Mr. C. C. Agar, Albany, N. Y.: I spoke about hydrated lime in powdered form. I saw a number of plants in New York State where it was very effective in controlling several problems in plant operation. Probably the most important control measure we have noticed has been the decrease in the quantity of scum present in the gas tanks. Daily application of lime—hydrated lime in powdered form—has not only resulted in improvement in the condition of scum but also improved the digestion and reduced odors.

Sewage Plant Tests and Demonstrations*

BY F. E. DANIELS

Pennsylvania Department of Health, Harrisburg

Laboratory control of sewage disposal is most important. Laboratory data, *when understood*—and I wish to repeat that, *when understood*—point out defects to be corrected, and show the true values of the results obtained.

In the absence of a trained personnel and a well equipped laboratory, the operator can and ought to do many simple tests which will enable him to keep a better check on the different units of his plant, and to *record* the results of his efforts. In so many cases one feels like quoting from the General Confession of the Morning Prayer: "We have left undone those things which we ought to have done; And we have done those things which we ought not to have done; And there is no health in us."

And we might also add with much feeling: From the individual who goes about testing here and there all over the place without knowing what he is doing, *Good Lord, deliver us.*

Here are a few cautions:

1. Tests made on samples which are not representative are worthless.
2. Tests made on samples not properly preserved are worthless.
3. Tests improperly performed are worthless.
4. Tests not understood are worthless.
5. Tests not properly interpreted are worse than worthless.
6. Tests on the same flow without some treatment unit between the points of sampling make extra work and the checks are not warranted.
7. Tests unsuitable to the kind of sample are either worthless or give results which are of no practical importance.

From another point of view, let me emphasize that laboratory tests are no substitute for keen observation and practical experience. A trained inspector can in most cases tell in a few minutes by observation alone whether or not the plant is working properly or what should be done with it. An interesting case has recently come to my attention. I know of a town which fifteen years ago built a sewage plant containing, among other units, three contact beds. The beds were controlled, *i. e.*, dosed in rotation, by air-lock siphons which depend upon the filling of the chambers for the air bells by sewage from the bed through a pipe leading from each contact bed to its respective air-bell chamber. Recently a man was called from the New York office of the siphon manufacturer who found that two of these pipes had for some reason or other been plugged by the contractor when the plant was built and had never been opened. For

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fifteen years, two of the beds had failed to function and the trouble was never located by any one! Will you please tell me what chemical test you could prescribe for such a case?

In some cases, however, remedies are not so easily indicated, and careful study and tests are needed before the plant can be made to function properly. Frequently, the records of suitable tests are the *only* means the operator or inspector has to *prove* to others the exact status or performance of the plant.

Remember this: *Your tests are never any better than your accuracy of sampling.* Your sample should be a portion of the material which truly represents the whole now and, perhaps, later to come, and should be collected and preserved in such a manner as not to spoil or interfere with the accuracy of the contemplated tests.

SAMPLING: More persons take samples than make tests. And even the lowly sampler should know what he is about and should be treated with sufficient courtesy to let him understand why such samples are needed and how they should be obtained. He should do useful work and not something just because he is told to do it.

For the methods and cautions to be employed in making sewage plant tests, the reader is referred to well-known publications, particularly to "Standard Methods of Water Analysis," various text books and the pamphlets issued by several of the states, such as that by the Division of Sanitation of New York.

Finally, let me give you a word of advice: Be careful how you associate with sewage. It is not very respectable to say the least; its very beginnings were foul. Be careful not to let sewage come in contact with cuts or abrasions on the skin. That is a good test to keep away from! Leave the results of such tests with their victims in the graveyard. Be careful to wash the hands well before taking or handling food and do not let flies have any access whatever to your lunch.

Sewage is a bad actor and should be treated with a firm hand and kept in its place; but withal, under proper care and treatment, it may be reformed to serve a useful purpose.

Discussion of Paper by John H. Fertig, "Application of the Sewer Rental Law"*

Professor E. D. Walker, State College: The whole matter of sewer rentals is so tied up with the larger problem of sewer assessments that I think it would give us a little better view of the picture to include certain matters in addition to those mentioned in this paper. I would therefore start with the consideration of the Massachusetts Statutes. There is in the *Engineering Record* of about forty years ago an abstract of a report by Mr. F. Herbert Snow, then City Engineer of Brockton, Mass., and later Chief Engineer of the Pennsylvania Department of Health, which, I believe, formed the basis of the Massachusetts Statute. That law provided, and I do not know of any recent amendment, that not less than one-fourth and not more than three-fourths of the cost of building a sewer system should be paid for from the funds in the municipal treasury provided by general taxation, and of the remaining portion a part should be paid for by assessment upon the abutting property; in addition, a sewer rental charge should be collected from the properties connected to the sewer. This, I think, comes as near as anything that has been devised for providing equitable assessments.

As Mr. Fertig mentioned in his paper, a sewer system anywhere in a municipality is a benefit to all the people of the community, regardless of whether they can avail themselves of the sewer system immediately or not, as it reduces the menace to public health. Disease may originate in one part of a community and spread to other parts. Then again, properties abutting directly on the sewer are benefited and have their values increased whether developed or undeveloped. Therefore, something should be paid in the way of an assessment by abutting properties, and it has been pointed out that the user should pay in proportion to the use.

I happen to know something about the method, as operated in one place, of basing the sewer rental on the water meter readings. In cases where meters are not in use, non-metered houses are visited and the facts ascertained as to the occupancy, whether boarding houses, family residences, etc., and charges for sewer rental made accordingly. In the case of manufacturing plants where the water passing through the meter enters into the products sold, such as bottling works for instance, allowance should be made for that part of the water which does not reach the sewers.

Mr. Fertig has pointed out that the specific provisions by statute for the collection of sewer rentals in Pennsylvania is apparently of recent origin. About twenty-five or thirty years ago I was requested to address a meeting of citizens of the Borough of Chambersburg on the subject of sewer assessments, etc., and prepared an outline of a method similar to the Massa-

* THIS JOURNAL, 5, 967, November, 1933.

chusetts system to present for consideration. This included a payment of a part of the cost of the sewers from the general treasury, a part by assessment on the abutting property, and also provided for an annual rental charge to properties using the sewer. Before the meeting I was privileged to talk over the proposition with Judge Stewart, who I was informed was considered an authority on the law of special assessments in Pennsylvania, and was told that such a system would be perfectly legal in Pennsylvania.

At that time the statute authorized a borough to construct sewers and "to assess the cost thereof as a sewage tax upon the property adjoining or adjacent to the same, either by the foot front or in such other manner and in such proportions and amounts as to the burgess and town council may seem just and equitable." A later section in the same statute read "Provided, that nothing in this act shall prevent the construction of any public sewer and the payment for the same by general taxation, when the same is for the public health and general welfare of said borough." Later I was told by another attorney that such a system would not be possible under the laws of Pennsylvania. Shortly after that there was a decision in a case brought against either the Borough of Warren or the Borough of Kane in which the decision of the court upheld the right of the borough to make assessments, according to my recollections, involving at least a part of the methods mentioned. Whether this decision was upheld by the higher courts or not, I do not know.

It would seem that there are some other matters that might be worth considering in this connection. It is of course appreciated that laws and court decisions are different in different jurisdictions, but in some other jurisdictions it has been held that where a municipality carries on a public utility business for the convenience and benefit of its citizens it has the rights of a public utility corporation. I do not know whether or not this point has ever been raised in Pennsylvania, but it would seem to be pertinent to such a case.

One of the cases in another jurisdiction was where a municipal water department established rates to make the water department self supporting, charging rates on the same basis as would be charged by a water company, thus avoiding the necessity of making up deficiencies out of the public treasury. Rates were charged to all consumers, including other city departments, on the same basis. All of the money went into a fund which was at the disposal of the water department. Some citizens objected because of the high rate but it was ruled that a city water department had the right to make its operations self sustaining. In the case of a public service corporation operating a public utility it has the right to collect rates sufficient to maintain its plant and also to provide for extensions, and to provide for the retirement of indebtedness, if any, incurred in the original construction. So far as the Governor's veto of the bill referred to

is concerned, of course, we can see the ground for it, but I fail to see any equity in permitting a private corporation to pay its indebtedness in connection with the construction and operation of a public utility by rates charged to its consumers and denying the same right to a municipality operating a sewer system.

Mr. Grant M. Olewiler, Lower Merion: Mr. Fertig has referred to a statute covering third-class cities, which would permit them to collect a rental on a sewerage system which was purchased from a private company This matter should be considered by our association and we possibly could make recommendation as means whereby this could be passed through the legislature.

The article in THIS JOURNAL by Childs and Schroepfer is a good article—it covers not only this state but a number of states and it goes into very minute detail upon sewer rental and how it is fixed by various communities. If you are considering the adoption of a sewer rental in your town, the first thing you should do is to be sure the people who have charge of the work know what they are talking about. In our community the people are still asking when the rental is going to stop. In 1904 they were told it would stop when the first bond issue had run out. The commissioners themselves did not understand the rental plan. The people were told it was to pay for the construction cost of the sewer, but after that the charge was made to pay for the operation and maintenance of the sewer. The people became dissatisfied because the sewer rental did not stop. The construction of a sewer in one section of a municipality may provide benefit in another part but in our community the situation is a little different. We have six miles of sewers built at the lower end of our township but none at the upper end. To say that the construction of a sewer system in one corner of the township provides benefit for those over six miles away is stretching it. It is really unfair to people who live so far away and do not receive any benefit.

Acting upon this idea, we have in our township nineteen sewer districts so you can see that by the sewering of five of them which have later been extended to nine we did not cover a large part of our territory. But there must be some way to collect for the maintenance of sewers as well as for their original cost. One suggestion has been made; the counting of the voters. You might make two counts a year but you could not be sure everybody paid a fair proportion of the cost by this method, and it would take two persons to do this work.

In making your rates you should leave a good bit of your rate making to a committee of your commissioners, your aldermen or the town governing body.

Mr. F. C. Foote: I want to call your attention to the fact that we must wait until 1938 to amend the Constitution. Many communities

would like to take advantage of Federal funds under the Federal Act. Many communities would like to build sewers. Although the sewer rental law permits only construction costs and in some cases interest charges to be included, it is a point that this Association could well get back of this matter and put forth an amendment to the State Constitution permitting communities to increase their indebtedness or to make capital expenditures for sewers, providing sufficient revenue were raised from sewer rentals to pay for them. We have not acted upon the Committee's report. I suggest that the Committee be enlarged and continued to consider that point.

Mr. Fertig: If you are contemplating my suggestion of fostering an amendment to the Constitution, it might be well to consider the redraft of the amendment that was adopted in 1913 with respect to railways and waterworks. That has lately received construction from the Supreme Court to the effect that you can only issue bonds for the original construction or additional acquisition of waterworks.

Mr. Foote: There are three Acts passed by the West Virginia legislature. If our Constitution could be amended along the line of these three Acts to permit the construction of sewers and waterworks by municipalities with the issuance of revenue bearing bonds, exclusive of any indebtedness of the municipalities, permit the collection of sewer rentals to provide money for bonds and operating expenses, and that Council can take such action regardless of the vote of the people, except in cases of purchase, I believe it would be a good thing.

Mr. Fertig: In the 1931 Session there was a bill introduced to amend a section of the 1913 law which had the approval of boroughs and municipalities. Has the Committee taken this into consideration?

Mr. J. F. Laboon, Pittsburgh: I have been studying that law too and I discovered one or two phases which I would much rather see adopted. The West Virginia laws provide for a Sanitary Board which must be created by city council. The board has full power to assess rates but these rates shall be collected against property owners and liens filed against properties. For the more usual form of rate schedule whereby you are going to charge for sewer use in proportion to the metered consumption of water, it is well to bear in mind that in many cases the water rental is collected from the water user, as contrasted with the law in which the rental must be collected from the property owner. The Sanitary Board has three members and there are two appointees and they have full authority to conduct the business of a utility, using the sewer system as a means of collecting revenue.

Editorial

The Sludge Index

Activated sludge is more protean in character than it is protein in composition; its volatile content confers a volatility or temperamental instability that is reflected in the occasional difficulties of "bulking" or rapid change in specific gravity, growth of "-thrix" organisms or sliminess, and in aggravated cases practically complete loss of sludge. The chemical, physical and biological factors which influence the character of activated sludge are so complex that it is truly remarkable to find any degree of stability whatever in its composition and properties.

From a practical standpoint the settleability of activated sludge is one of its important properties. The earlier control test for determining the amount of sludge to be carried in the aeration tanks depended solely on the per cent of sludge settled in a specified time, usually one hour, in a graduated cylinder. Later, when it was found that, due to the swelling and shrinking of the sludge floc, the actual weight of sludge might vary as much as 100 per cent in the settled volume, practice veered toward determination of the gravimetric concentration of sludge in the aeration tank, expressed in parts per million or per cent by weight. Both volumetric and gravimetric tests are now used by practically all activated-sludge plant operators, and the data thus obtained make it possible to determine the ratio of weight to volume, or in other words to compute the "sludge index."

In the course of the investigations of some twelve sewage treatment works in the United States in 1920, Theriault computed the ratio of volume to weight of the activated sludge in four activated-sludge plants in Texas. These ratios are shown on page 24 of *Bulletin* **132** of the U. S. Public Health Service, entitled "Sewage Treatment in the United States." He states "it seems logical to conclude that the volume occupied by the sludge bears a rather definite relation to the actual weight of sludge present as long as the character of the sludge remains the same. This relation is, however, affected to a surprising extent by any change in the character of the sludge." The "sludge ratio" reported by Theriault was determined by settling sewage and sludge from the aeration tank effluent in a 1000-cc. graduated cylinder for 15 and 30 minutes, determining the total suspended matter in parts per million, and dividing the parts per million by the cc. per liter after 15 or 30 minutes settling. The weight was thus in the numerator and volume in the denominator. The ratios reported

varied from 40 for what was considered very good sludge, down to 5 for bad sludge, based on the 30-minute results.

In 1931 Donaldson reviewed Theriault's work and reported additional data from Tenafly, N. J. (THIS JOURNAL, January, 1932, page 56). Donaldson suggested the term "sludge index," which is now generally used. He settled for 30 minutes in a 1000-cc. cylinder, determined per cent dry solids by weight, and divided the per cent by weight, times 100, by the per cent settled in 30 minutes. The sludge index was therefore 10 times the sludge ratio computed by Theriault.

In a more recent publication Haseltine (THIS JOURNAL, May, 1932, page 465) expressed a sludge index for Salinas, Cal., activated sludge as the "quotient of the suspended solids in the mixed liquor, expressed in parts per million by weight, divided by the per cent of sludge by volume in the mixed liquor, as determined after standing 30 minutes in a 500-cc. graduated cylinder." The Haseltine index was thus 100 times the Theriault sludge ratio.

Rudolfs (THIS JOURNAL, November, 1933, page 953) refers to a sludge index which was computed as the quotient of the parts per million of suspended solids divided by the per cent of sludge settled in 30 minutes *times 100*. This gives an index identical with Donaldson's, although computed in a different way.

In all these computations the weight of sludge solids, in parts per million, has been in the numerator. This means that bulking sludge is expressed by a diminishing numerical index. This has seemed to some investigators to be inconsistent with the concept of bulking, consequently they have turned the equation upside down and placed the results of the settling test in the numerator, thus giving an increasing numerical index for bulking sludge. This index has been used by Palmer and Smith at the Chicago North Side and Calumet plants, at North Toronto by Fales and Coburn, at Milwaukee by Heisig and by Kraus at Peoria.

Because of this confusion in methods of determining and computing the sludge index it seemed to the writer to be desirable to summarize the procedure at the more important American activated-sludge plants, or research stations, and to recommend a uniform technique and method of computation, to the end that results would be comparable. Eighteen questionnaires were sent to chemists or plant operators. Replies were received from all. Two were eliminated because the pre-aeration process in use is operated with practically no activated sludge; three more operators described the technique used in the settling test, but they do not compute the index. This leaves thirteen who reported the procedure and index, and sixteen the procedure alone.

Of the sixteen, fourteen use 1000-cc. graduated cylinders, one 500 cc. and one 250 cc. The settling period is 30 minutes at twelve plants, 60

minutes at the additional four. The results are reported in per cent of settled sludge by fourteen operators, in cc. per liter by two. Suspended solids are reported in parts per million at twelve plants and in per cent at the other four. The index is computed according to Donaldson's method at six plants, according to the inverse method at four, according to Haseltine's method at two and by Theriault's method at one.

Donaldson's index varies from approximately 0.3 for bulking sludge to 2.0 for rapidly settling sludge; Theriault's from 1.1 for bulking to 25.0 for rapidly settling sludge; Haseltine's from 30 for bulking to 170 for rapidly settling sludge; and the index used at Chicago, Milwaukee and Peoria, and by Fales and Coburn, from 40 for rapidly settling sludge to 200 for slowly settling or bulking sludge.

This last index seems most logical to the writer. It expresses the cubic centimeters occupied by one gram of sludge, and increases with increasing bulk.

With these data at hand, the following technique and method of computing the sludge index is proposed:

> The sludge index (S. I.) is the volume in cubic centimeters occupied by one gram of sludge after settling 30 minutes. The sample is collected at the outlet of the aeration tank, settled 30 minutes and the volume occupied by the sludge reported in per cent. The sample is thoroughly mixed, or the original sample taken, and the suspended solids determined and reported in per cent by weight. The sludge index is computed by dividing the result of the settling test, in per cent, by the result of the determination of suspended solids, also in per cent.

While this may involve a change in method of computation for some operators, it is a simple transition. The Donaldson index can be converted to the S. I. by dividing it into 100, the Theriault by dividing into 1000 and the Haseltine by dividing into 10,000.

SLUDGE INDEX

Plant	Average or Normal	Min.	Max.
Chicago, Calumet	55	29	100
Chicago, North Side[a]	65	35	100
Cincinnati, Ohio, U. S. P. H. S.	—	40	910
Hagerstown, Md.	150	68	454
Indianapolis, Ind.[b]	185	74	312
Lima, Ohio[a]	71	59	115
Milwaukee, Wis.	75	44	100
New Jersey Exp. Sta.	—	35	500
North Toronto, Ont.	—	40	200
Pasadena, Cal.	104	53	262
Peoria, Ill.[a]	100	—	250
Salinas, Cal.	—	83	167
San Antonio, Tex.[c]	168	72	305

[a] 60 minutes settling [b] 250 cc. cylinder [c] 500 cc. cylinder

The data sent to the writer by thirteen chemists have been computed to the proposed sludge index and the results averaged. In most cases the results cover a year's operation. The data are shown in the accompanying table.

These indices are subject to some revision since some replies listed only the normal index or included only partial data, but it is believed that the results are fairly representative for the plants listed. Further work is necessary to demonstrate the monthly variations, and their relation to the efficiency of operation. In order to obtain an authoritative comparison of sludges from various plants there should be available a full year's record, but the first step toward uniformity has been taken if a standard test is used by all. The writer therefore urges the use of the recommended procedure and computations indicated above, starting with the year 1934; at the end of the year a comparison of the accumulated data should be of considerable interest. As an additional test of value, the determination of volatile content of the sludge should be included.

F. W. MOHLMAN, *Editor*

Employment Service

(1) DESIGNER thoroughly experienced in design and construction of sewage treatment plants. Just completed one year with general contractor on sewage treatment plant job. Previous four years drafting and design work in sanitary engineering. Total experience twelve years since graduation. Age 37. Married. Assoc. Mem. A. S. C. E.

(2) M. S. in SANITARY ENGINEERING, 1932, Michigan State College. Seven years with the Michigan State Highway Commission. Municipal engineering, including construction of water mains and sewers. Assistant instructor in sewage operators school. Publications on trickling filters and stream pollution. Age 31. Married.

(3) SANITARY ENGINEER, graduate M. I. T., four years experience in design of sewers and sewage treatment works, five years experience in investigating industrial wastes, designing and operating sewage testing stations, and investigating and developing methods and apparatus for sewage treatment. Three years as asst. supt. of large activated-sludge plant. Desires position to design or operate treatment works or to aid in the development of new processes and apparatus for sewage treatment. Age 36. Married.

(4) CHEMIST AND BACTERIOLOGIST, university graduate, six years superintendent of water filtration plant, past five years in sewage works laboratory, in charge of plant control. Recent experience in sludge filtration and disposal. Age 37. Married.

(5) SANITARY ENGINEER, M. S. from Michigan State College. Experience in highway and railway work. University work in soil bacteriology. Age 25. Single.

(6) SANITARY CHEMIST AND BACTERIOLOGIST, B.S. in Chemical Engineering, M.S., four years experience in sewage and water treatment, principally research and development at state experiment station, recently with prominent consulting sanitary engineer, publications. Age 27. Single.

(7) SANITARY ENGINEER. More than ten years experience in designing, building and servicing mechanical equipment used in sewage treatment works, such as screens, clarifiers, digesters, aerators and pumps. Design and construction of paper mill and beet sugar factory. Age 37. Married.

(8) SUPERINTENDENT of sewage works. Ten years experience as Superintendent of small Iowa sewage treatment plant. Has also had charge of municipal garbage incineration works. References. Age 39. Married.

(9) SANITARY ENGINEER. Technical school graduate, nine years experience sewage collection and treatment and water distribution and purification. Investigations, reports, design, construction, operation, chemical and bacteriological analyses, research and development, sanitary equipment sales and promotion. Familiar with engineering state and municipal organizations in eastern and mid-western states. Desires position as sales engineer, designer, or operation superintendent. References and details of experience on request. Remuneration secondary to permanent connection with future. Age 30. Married.

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Reviews and Abstracts

H. W. STREETER

Remarks on the Flies Breeding in the Bacteria Beds at the Knostrop Sewage Works, Leeds

By J. E. B. Dyson and Ll. Lloyd

The Surveyor, **84**, 335–7, 341–2 (October 20, 1933)

This paper, presented before the Northeastern Branch meeting of the Institute of Sewage Purification on October 14, 1933, a progress report on studies of the fauna of sprinkling filters, brought out much interesting discussion on the subject.

One outstanding benefit of the higher forms of life on bacterial filters was clearly demonstrated by Parkinson and Bell, who showed that *Achorutes viaticus*, by feeding on the dense growths of algae and fungi, prevented clogging and ponding and moreover brought about greater reduction of free and albuminoid ammonia. Reference is also made to the work of Meiklejohn on the production of ammonia by soil bacteria in the presence and absence of *Colpidia*, who found that this protozoan prolonged the activity of the bacteria by keeping their numbers in check or, as suggested by Cutler and Bal, that though preyed on the bacteria are kept in a state of physiological youth. This theory would explain the increased ammonia production resulting from the activity of *Achorutes*. (This same theory, independently advanced, is propounded by Butterfield, Purdy and Theriault in explanation of the different degree of biochemical oxidation of organic matter in water by bacteria obtained in the presence and absence of plankton. See *Public Health Reports*, **46**, 393–426, Feb. 20, 1931. Abstractor.) If this theory is sound, similar beneficial effects must be produced by other higher organisms also, such as insect larvae and worms which graze over the surfaces of the filter medium. In any event insect larvae do scour the beds and the mature flies become a neighborhood nuisance only when they emerge in swarms. They cannot be considered dangerous because they enter houses only by accident or in seeking protection from strong light or wind.

The fauna of bacteria beds must be sufficiently hardy to withstand sudden drenching and swift flowing water alternated with practically dry periods sometimes of several days, even in hot weather; they must exist practically in the dark and therefore feed on plant growth void of chlorophyl and must survive in water of relatively low organic content. On

the other hand, they are favored by reasonably equable temperatures in the bacteria beds and have few enemies which prey upon them except some predacious beetles and their larvae, spiders and parasitic wasps. Also their food supply is spread quite uniformly throughout the depth of the bed in contrast to that of the mud dwelling larvae of ponds where a very shallow bottom zone supports such life.

The study here reported upon has been confined to the flies caught in traps on the beds and to their larvae near the surface and by one excavation throughout the depth. The beds have tight concrete walls, are composed of water worn pebbles or broken limestone, and are equipped with traveling sprayers which apply the sewage liquor in sheets or in drops. Comparisons were made of the fly breeding capacities of the two kinds of medium and two methods of sewage distribution.

Notes on Numbers and Habits of Flies Observed.—*Spaniotoma minima*, the most abundant species found, is a minute black fly 1.5 mm. long. It is active in day time, mates on the walls, pipes and surfaces of puddles and deposits its eggs in small clusters embedded in mucus. It increases in numbers in warm weather, ranging from 4 per sq. ft. per day in December to 431 in August. As many as 1000 per square foot per day have been trapped on limestone beds where it appears to be twice as prolific as in gravel beds. It resists drying of beds and emerges on the dry parts and apparently prefers sheet sprayed filters to those that are drop sprayed though this is not conclusive. It breeds to a small extent in aeration channels.

Metriocnemus hirticollis and *M. longitarsus* are both about 3.0 mm. long, are diurnal and the males are very similar in appearance. *M. hirticollis* is the more abundant of the two, the females of which are brown with lyre markings on the thorax, while *M. longitarsus* is almost uniformly dusky. Eggs are laid just below the surface stones in mucus masses. The young larvae drop to the lower parts of the bed and on approaching maturity migrate upward and pupate in a gelatinous matrix near the top surface. These species favor colder weather and appear to be affected by drying of the beds. Thus, on an active filter in August the proportion of *Spaniotoma* to *Metriocnemus* was as 10 to 1 but on a bed that had rested it was 50 to 1. Also the latter species was 3 times as numerous on wet beds as on dry ones while with the former species the ratio was as 8 to 10.

Chironomus dorsalis: This large green fly breeds from red larvae that may be found in shallow accumulations of water in the aeration channels. It shelters in dusky places, although it is not so averse to light as *Psychoda*. It does not breed in the beds to any extent.

Tangtarous atrofasciatus is similar in appearance and habits to, but about one-third the size of *C. dorsalis*. It shelters on the lee of the rails which carry the sprayers and on the pipes.

Psychoda severini and *P. alternata:* The former has smoky white wings with no spots while the wings of the latter are densely clothed in black and white hairs and have margins marked with black spots. Both sexes occur but males are relatively scarce. *P. alternata* was very abundant in a hot, dry period, sheltering in dense masses under the pipes when no wind blew but dispersed in a moderate breeze. *P. severini* favors cool weather, in contrast to *P alternata*, and the mature larvae migrate to the surface as do those of *Metriocnemus*. Roughness of the filter medium favors their development because of the security provided for the larvae and pupae which are air breathers. Such crevices also give shelter to the flies, protecting them from light, wind and spray. They rest in clusters which are surrounded by dry areas. It is estimated that they may develop either in pebble or limestone beds at the rate of between ten and twenty millions per acre of beds per day. Trapping showed the following ratios of production between: limestone and pebble beds as 16 to 10, drop sprayers and sheet sprayers on pebbles as 17 to 10 and on limestone as 14 to 10, dry parts of beds and wet parts were less than 2 to 10.

Other Diptera. Spathiophora sp., a medium-sized predacious insect, was trapped in summer at the rate of 2 to 3 per sq. ft. per week. Its larvae, of typical maggot form, were abundant just below the filter surface. *Limosina*, a small sturdy fly emerged at the rate of 1 per sq. ft. per day in summer and was very abundant on the nearby walls and grass. *Mycetophilidae*, a fungus gnat, was observed at times in small numbers. The minute midge *Culicoides pulicaris L*, a blood sucking insect, was found in the traps several times.

Conclusions.—The authors conclude that, regardless of the composition of the filtering material, grazing organisms will develop in numbers sufficient to keep the beds in working condition but that for prevention of excessive fly breeding screened, smooth pebbles are to be preferred. The full dispersing power of the winds is interfered with by shade trees or shrubbery near the beds.

Discussion

Mr. J. T. Tompson of Leeds in opening the discussion emphasized particularly the seasonal changes in fly population. In normal times *Metriocnemus* predominated, occurring in large masses on still days but this year the smaller *Spaniotoma* had replaced them. Also *Psychoda*, normally few, had this year increased in numbers. He was convinced that the gravel beds at Knostrop was the reason for the lack of fly nuisance there.

Mr. H. D. Bell of Barnsley, who has done much of the work with *Achorutes*, was in agreement with the theory of increased purification resulting from their grazing action which fact he had observed in 1913. Worms, larvae, insects, etc., might have the same beneficial effect on the bacterial

population and certainly maintain free air passage through the filter beds which should encourage aerobic bacterial action. He agreed that the best way to reduce the fly nuisance without detriment to filter efficiency was by methods outside or at the surface of the filter beds. Insecticides effective against *Psychoda* larvae for instance, which are most numerous at from 1 to 6 ft. depth, would be reflected in decreased purity of the filter effluent. However, dilute solutions penetrating only 3 or 4 inches would kill the flies near the surface. He had had fairly successful control by spraying the outside filter walls where large numbers of *Psychoda* emerged. Trees and long grass near the filters which provide shelter for the adult flies should be removed wherever possible. In contradiction to the authors he believed that a filter medium containing cavities and with a rough surface was best because this type favored the propagation of *Achorutes*, offered a greater surface for bacterial growth and resulted, consequently, in fewer flies.

Mr. W. D. Scouller of Huddersfield observed that *Psychoda* emerged only at temperatures above 50° F. and during cloudy days or at times when clouds were passing before the sun. He had not seen many flies emerge through the sides of the filters at Huddersfield but mainly on the filter surface. He believed smooth filtering material reduced the number of flies but was not so effective as slag in purifying sewage because of the smaller surface area of gravel. He had found *Psychoda* very resistant to streams of water and had previously doubted whether the method of sewage or water application would have affected the rate of fly production. He agreed on the beneficial effects resulting from attention to filter surroundings when flies emerged from the beds. However, unless there was a method of controlling them, *Psychoda* would come out by the millions and an aerial nuisance was bound to result, elimination of trees and grass being only a palliative and not a cure. J. K. HOSKINS

Sewage Purification at Exeter

ANON.

The Surveyor, **84**, 265–7 (Sept. 29, 1933)

A new disposal works of the "Simplex" type of activated-sludge treatment was placed in operation on September 20, 1933, by the city of Exeter, England. The existing sewerage system and four treatment plants, two on the septic tank and two on the broad irrigation principle, had become overloaded by reason of recent rapid developments. Accordingly, there was designed and constructed a new interceptor system, outfall syphon and central purification plant.

The main intercepting sewer about 2 miles long, $^3/_4$ of a mile of which

is in tunnel through rock, ranges in diameter from 48 in. to 54 in. and is constructed of brick ring or concrete. A 15-in. rising main and syphons convey the sewage under the Exeter Ship Canal and River Exe to the site of the treatment works. Because of the low elevation of this side and consequent danger of flooding, a strong embankment carried 3 feet above the highest recorded flood level was built around the area. All of the 10,500 cubic yards of concrete used in the tank construction was mixed at a central point and distributed from a 180-ft. tower through chutes.

The purification plant was designed for 70,000 people, contributing a dry weather flow of $2^1/_2$ m. g. d. The sewage first flows through one of 3 detritus chambers, each of 25,000 gallons capacity, and then through one of 3 mechanically cleaned, electrically operated, fine screens of the Simplex grab type. Preliminary sedimentation is next provided in 16 tanks square in plan with hopper bottoms and with a total capacity of 833,000 gallons or 8 hours dry-weather flow. Sludge is removed from these tanks by gravity and pumped to sludge drying beds.

All settled sewage up to 3 times the dry-weather flow passes to the series of aerating tanks having a total capacity of 1,682,000 gallons or 16 hours d. w. f. Eight parallel units are provided with five pockets in each unit and supplied with Simplex surface aeration cones. The effluent from the aeration tanks passes to the eight units of final sedimentation tanks which have a total capacity of 648,000 gallons. Sludge is removed by gravity through automatically operated valves which open at predetermined intervals and then is pumped either to the inlet end of the aeration tanks, or the surplus to the inlet end of the preliminary sedimentation tanks. The excess, settled storm water and the treated effluent are discharged to the River Exe.

The preliminary tank sludge is dried on beds of 17,800 sq. yd. area, divided into 64 units, each bed being equipped with a special decanting valve for removing the supernatant water. The liquid from the sludge beds is returned to the incoming sewage for treatment.

The cost of the outfall syphon and disposal works was approximately £88,000; and of the main intercepting sewers, about £51,000. Plans and photographs of the treatment works accompany the article.

J. K. HOSKINS

Cannock Sewerage and Sewage Disposal

ANON.

The Surveyor, **84**, 35–56 (October 27, 1933)

The new sewerage and sewage disposal works of Cannock, Staffordshire, located on the $21^1/_2$-acre site of the old land treatment plant was recently opened by local officials. The new works were designed to supplement

and eventually replace the existing plant, the combined capacity of which is now 1 m. g. d. The total cost of the improvements was £67,500 including £18,500 for new sewers.

The treatment works, illustrated by a general plan which accompanies the article, consist of screening detritus chambers each in duplicate, a group of four sedimentation tanks of the continuous, horizontal flow type, three storm water tanks, two octagonal dosing chambers with automatic syphons, seven bacteria beds each 95 ft. in diameter and 5 ft. deep, five secondary settling tanks of the upward-flow type, constructed with inverted pyramidal batteries and twenty-four under-drained sludge lagoons, 5470 sq. yd. in area.

The screens are operated by hand and the detritus tanks are equipped with power-driven elevators. A three-times dry-weather flow-gauge and recording apparatus are fitted to the 70 ft. long storm water overflow weir. Automatic syphons in the dosing chambers are arranged to operate either in unison or alternately. The sewage is distributed on the bacteria beds by rotary sprinklers. The humus sludge and supernatant water pumps are motor driven and have a capacity of 200 gallons per minute. The new plant eliminates further necessity of treatment of any sewage of the municipality by surface irrigation. J. K. HOSKINS

Sewage Disposal in the Thames Estuary

ANON.

The Surveyor, **84**, 331–2 (October 20, 1933)

The borough of Southend-on-Sea has completed the construction of new sewage treatment works, including necessary mains, sea outfall and effluent conduit at a cost of over £500,000.

The site of the works at Prittlewell is not an economically suitable one, as the low level sewers reach the plant 45 feet below ground level. This high pump lift has been reduced by locating the purification works in the bottom of a gravel pit, which arrangement allows the high level sewers to discharge to the new works by gravity in contrast to the pumping previously required.

The new plant is designed to treat 5.5 m. g. d. of dry weather flow of sewage and three times this volume of storm flow, although the present dry-weather flow is 3.5 m. g. d. The maximum storm flow that may be received from the sewerage system is 47 m. g. d., so that the new and old conduits and outfalls at the plant have been combined to accommodate this amount. Treatment consists of coarse screening, grit removal and plain sedimentation with sludge disposal. The effluent is discharged through a 5-ft. diameter conduit leading to the beach from which the out-

fall, a 5-ft. cast iron pipe line, extends into deep water below low water mark.

The two grit tanks are 20 ft. square in plan and have a water depth of 2.5 ft. Only inorganic grit is deposited in these tanks and is moved to one side by revolving arms and then raised by oscillating rakes and an endless bucket chain to an overhead hopper.

The three sedimentation tanks are each 100 ft. square and 12 ft. deep, with a total capacity of $2^1/_4$ m. g., or at the maximum dry-weather load a detention period of 12 hours d. w. f. Sewage enters the tanks in a thin film uniformly distributed over the full tank width. Sludge is removed at least once or twice daily, and without emptying the tanks, by mechanically rotating machines of the Dorr-Oliver type which force the settled material slowly along the bottom of the tanks to the center sludge outlets.

The sludge is pumped to old tanks at the higher level of the old sewage works where it is allowed to settle. The concentrated sludge is then pumped through a 9-inch cast iron pipe line $4^1/_2$ miles long to a trenched drying area. It is ultimately sold to farmers for fertilizer. J. K. HOSKINS

Sewage Disposal Improvements in England

Three municipalities have installed new sewage treatment works, all of which are described in *The Surveyor*, **84** (November 3, 1933)

Ellesmere Port Sewerage and Sewage Disposal. Pp. 377–8.—The urban district of Ellesmere Port, Cheshire, has recently completed two sewage disposal plants of the sedimentation-sprinkling filter type at a cost of £113,000 to serve its population of about 24,000. The general plan of both plants accompanies the article.

The Little Stanney works on a site of $17^1/_2$ acres consists of duplicate screening and detritus chambers, six concrete sedimentation tanks with a total capacity of 315,000 gallons, two octagonal dosing tanks each of 2000 gallons capacity, six circular bacteria beds 5 ft. deep and 95 feet in diameter and two circular humus tanks 22 feet in diameter and 24 ft. deep. For sewage in excess of three times the dry-weather flow, five rectangular concrete storm water tanks are provided, holding a total of 156,000 gallons. The sedimentation tanks are operated in parallel and are equipped with submerged weirs for sludge removal and with decanting valves for removing supernatant water. The sludge, together with that from the detritus, storm water and humus tanks, gravitates to a sump from where it is pumped to lagoons. The bacteria beds are composed of graded broken granite and are dosed in any desired combination by automatic rotary distributors. The humus tanks are of the upward flow type with cone-shaped concrete bottoms and vertical brick sides and discharge their ef-

fluent through an outfall sewer into the tidal section of the river Gowy. The sixteen sludge lagoons serve both the Little Stanney and the Town plants and have a total area of 3880 sq. yd. They have reinforced concrete floors and outside walls of earth covered with 2-inch concrete slabs. Drainage from these lagoons is pumped back to the inlet of the sedimentation tanks for retreatment through the works. The land adjoining the lagoons is used for irrigation of the supernatant water from the sedimentation and storm water tanks.

The Town Works consists of duplicate screening and detritus chambers provided with electrically driven raking and dredging apparatus, two concrete storm water tanks of 43,750 gallons capacity, four sedimentation tanks of 146,200 gallons' capacity, dosing chamber with two automatic syphons, three bacteria beds each 94 ft. in diameter and 4 ft. deep and two humus tanks, holding 29,170 gallons. All sludge from the various units gravitates to a sump and from where it is pumped to the sludge lagoons at Little Stanney, a distance of $1^2/_3$ miles.

Manchester Sewerage Works Extension. P. 384.—Extensions of the Davyhulme sewage treatment works of Manchester are almost completed and comprise three separate processes—air diffusion, "Simplex" surface aeration and bioaeration.

The new air diffusion plant is designed to treat 16 m. g. d. of dry-weather flow and consists of two independent units and one large plant, with four aeration units and a common sludge re-aeration tank. Each aeration unit has three channels 354 ft. long, 15 ft. wide and 15 ft. deep, providing a detention period of 14 hours. Aeration is by means of three longitudinal lines of diffusers in the channel floor. Each of the aeration units is served by 14 hopper bottom, upward flow settling tanks from which the activated sludge is returned to the re-aeration tank by gravity and air lifts.

The Simplex plant of 1 m. g. d. capacity has three aeration units 133.5 ft. by 33.5 ft. in plan and 15 ft. deep with three settling tanks for each, providing a detention period of 15.5 hours. Each aeration unit is subdivided into six aeration pockets fitted with uptake pipes and aerating cones. In operation the mixture of sewage and activated sludge passes six aerators in succession before entering the settling tanks.

The bio-aeration plant will treat 0.6 m. g. d. of dry weather sewage and consists of fourteen aeration channels 254 ft. long, 6 ft. wide and 3.5 ft. flow depth. The mixture of sewage and activated sludge is moved through the channels at 1.5 ft. per second by centrally placed vertical paddle wheels of 11 ft. diameter revolving 15 times per minute. The average detention period in dry weather is $18^3/_4$ hours, corresponding to a travel of 20 miles, although it is possible for some portion of the sewage to pass through the plant in 40 minutes. The aerated liquor passes to four settling tanks of the same type as those of the air diffusion plant.

Sludge from all three plants is pumped through a 10-inch force main $^3/_4$ mile in length to three storage tanks from where it flows by gravity to the sludge steamship and is barged to sea. A diagram of treatment operations of the Davyhulme sewage works accompanies the article.

Sewage Disposal at Warwick. P. 385.—Warwick has just opened its new sewage disposal works at Longbridge, constructed at a cost of £24,000 to serve a population of 14,500 contributing 608,800 gallons of dry weather sewage daily.

The sewage enters either or both of two detritus tanks and is then pumped to the disposal works 660 yards distant through a 15-inch cast iron force main. The sedimentation tanks are brick lined concrete 110 by 36 ft. in plan, 7.5 ft. average depth and have a total capacity of 346,000 gallons. The floors of 6-inch concrete slope to a center channel and from the outlet to the inlet end. Each tank is fitted with sludge valves and a floating arm. The seven filters are 87 ft. diameter and are composed of 5.5 ft. or a total of 8450 cu. yd. of washed granite graded from 4 inch at the bottom to $1^1/_2$–$^3/_4$ inch at the top. Three humus tanks, 78 by 33 ft. in plan, have an average depth of 1.75 ft. and have reinfored concrete floors 6 in. thick. All the sludge is pumped to existing sludge beds which are underdrained, and is then removed and stored in adjacent low ground. The clarified effluent is discharged to the river Avon. J. K. HOSKINS

Construction of Wards Island Sewage Treatment Works

BY RICHARD H. GOULD

Civil Engineering, **3**, 154 (March, 1933)

The project of the Wards Island sewage treatment plant for the City of New York has been described in *Civil Engineering* for November, 1931. Following are some of the characteristics of the plant as reported in the issue of current abstracts.

The plant is an activated-sludge plant of 180 million gallons daily capacity. It is designed to serve Harlem River and East River drainage. Water front interceptors center the sewage to two grit chamber installations on the mainland, from whence the sewage is delivered through two deep under-river tunnels to the Island. On the Island, pumps lift the sewage 45 feet.

The sewage flow is received to the extent of two times the dry weather flow, with the entire amount passing to pre-settling tanks. One and one-half times the dry weather flow is taken to the aeration tanks.

The works consist of—

8—100-foot square pre-settling tanks, equipped with Dorr removal mechanism. The tanks provide 1-hour detention.

16—Aeration tanks which inclusive of one spare, provide 5¼ hours detention for the average flow plus 25 per cent sludge return. The tanks are in four passes having a total length of 1380 feet and are 22 feet wide and 15 feet water depth.

32—Final settling tanks, equipped with Link-Belt removal mechanism. These tanks with two spares provide settling capacity at the rate of 1000 gallons per square foot per day for the average flow plus 25 per cent sludge return.

8—Return sludge pumping units in two stations, each unit having a capacity of 15 million gallons daily.

6—Motor-driven centrifugal blowers of 42,400 cubic feet per minute capacity at 7¾ pounds.

The project includes provision for storing and decanting sludge, which is barged to sea.

The whole project of plant and interceptors is estimated to cost about $24,000,000. The preliminary report covering the works was prepared in 1928, first bids were received in 1931 and operation in 1936 is expected.

Construction of the main contract inclusive of the pre-settling tanks, aeration tanks and sludge settling tanks, was characterized by speed and involved placing concrete at an average rate of 800 cubic yards per day from a central plant. An elaborate system of conveyors was used to transport concrete. Forms for the aeration tanks consisted of metal lined wood forms which were moved by motor truck. Most of the works lie above high water and the tanks are underlaid by underdrains equipped with check valves.

The construction of the treatment plant involves some 22 contracts. Two contracts (sea wall and aeration tanks, etc.) involve the preparation of 100 contract drawings covering 200 pay items. FRANK C. TOLLES

Intercepting Sewers and Storm Stand-By Tanks at Columbus, Ohio

BY JOHN H. GREGORY, R. H. SIMPSON, ORRIS BONNEY AND ROBERT A. ALLTON

Proceedings Am. Soc. Civil Engineers, **59,** 1289*

In 1908, the City of Columbus constructed comprehensive sewerage works inclusive of intercepting sewers and treatment plant. These were described by the present senior author in *Transactions,* Am. Soc. C. E., **67,** 206. The present paper is complementary to that of earlier date, in that it describes the enlargements and betterments made necessary by normal growth. The two papers thus constitute an unusual description and record of long-time development of city sewerage.

The Columbus program includes intercepting sewers, sewage treatment

* This is a paper of 36 pages octavo with photograph, diagrams and drawings

works and some changes in the collection system. However, the present paper concerns only the intercepting sewers and detention tanks which have been designed for storm water service only. The paper is particularly notable for its description of the first works of this kind to be built in the United States.

Changes Necessitated by Growth.—In the present development the East Side District, formerly with sanitary outlet through a pumping station, has been given a gravity outlet by the construction of the new Alum Creek intercepting sewer, which is a branch of the Olentangy-Scioto intercepting sewer, also new. The old Main intercepting sewer, inadequate in certain places and also having velocities which led to deposits (2.5 f. p. s. for half the length, and 1.8 f. p. s. minimum over long stretches), has been or will be converted to a sanitary sewer. Its function as the main interceptor of the city has been replaced by that of the Olentangy-Scioto interceptor. Improved service to certain areas has been afforded by converting combined systems to separate and by building supplementary storm drains.

Nuisance Conditions.—The city is served by two rivers, the Olentangy and the Scioto, and also by Alum Creek. Stream flows during the summer are quite low, much of the water (from the Scioto) being taken from above the city for local water supply.

Limited interceptor capacity has caused frequent overflows of mingled sewage and storm water to streams which, during certain portions of the year, at least, are unable to absorb the load. It is estimated that there were about 35 such overflows per year from each of the combined sewers. Contributory to this condition was the clogging of interceptor connections. As a result of these overflows, solids were washed out into the rivers and settled or became stranded along the banks.

Overloaded treatment works (Imhoff tanks and trickling filters) caused objectionable conditions below the city.

The influences of interceptor overload and of insufficient treatment works were verified by sanitary surveys which indicated that the streams above the city were in good condition but that progressive deterioration occurred through and below the city, as evidenced by low dissolved oxygen, oil films, discoloration, stranded solids and, in some places, offensive odors.

These several conditions led to the preparation of plans for improving the sewage treatment works (not yet built) and to works designed to prevent overflow of dry weather sewage, to minimize storm overflow, and to render the provisions for interception as nearly non-clogging as possible.

New Intercepting Sewers.—Three new intercepting sewers have been built, two of them to take unusually large contributions of storm water from the combined systems.

The basis for design of the interceptors included the following factors:

1. Capacity for 1960 conditions, which signifies an estimated population of 643,000 against the 290,000 of 1930.
2. Average sewage flow of 125 g. c. d. with 100 g. c. d. in separately sewered residential areas and 185 g. c. d. in industrial and commercial districts with combined sewerage. In aggregate, this leads to provision for a dry weather flow of 80 m. g. d.
3. Maximum rates of flow are from 2 to 4 times the average, depending upon the size of the contributing district (see Eng. N. R., 96:951).
4. The use of the "rational method" for portions of the interceptors which were designed for large contributions of storm water. Run-off coefficients were 0.75 for commercial, 0.45 for industrial, 0.35 for residential, 0.15 for parked areas. Inlet time was allowed at 10 minutes.

The rainfall curve used for the design of the interception of storm water was one which limited overflows in the central city to an average of 4 times per year. Read from the diagram reproduced in the paper, this would signify intensities about as follows:

5 Minute Duration	2.5	inches per year
10 Minute Duration	1.95	inches per year
30 Minute Duration	0.9	inch per year
60 Minute Duration	0.4	inch per year

In the case of the principal interceptor—the Olentangy-Scioto—the design led to interceptor capacities of 235–284 g. c. d. for normal flows and to capacities of 1660–2110 g. c. d. for mingled sewage and storm water in central city area.

Sewer Construction.—A variety of sewer sections of monolithic construction and with vitrified liner plates were designed to meet particular conditions. The sections are shown in the paper in some detail. Included was a river crossing where the interceptor was contained in a masonry dam of ogee section founded on timber piles and protected by up-stream and down-stream steel sheet piling cut-off walls. In another case, the sewer structure formed part of a channel improvement and was designed as the base section of a high retaining wall. Some of the work was built in tunnel with steel liner plates and under air pressures of 6–35 pounds. In this, headings averaged 1039 feet. Voids back of the liners were pressure-grouted at rates 0.14, 0.18 and 0.20 cubic yard per lineal foot of sewer in different sizes. Certain of the sewer sections were designed and built for internal pressures up to a 33 foot water head.

Regulators.—Interception of the flow from combined sewers is accomplished in a chamber which houses a sluice gate opening to the interceptor. The sluice gate opening controls the amount of diversion and the gates are set in fixed position to limit the average frequency of storm overflow to 4 times per year in the central city and to 8 times per year where outlets are more scattered.

Each regulator chamber is provided with marine lights and with flushing connections. In some cases manholes for the dumping of snow have

been included, and in one case provision has been made for lowering a boat into the interceptor, if necessary.

The paper includes a detailed drawing of a typical regulator chamber.

Storm Stand-By Tanks.—The storm stand-by tanks—2 installations on each of 2 interceptors—are located in down-stream margins of the city and above the sewage treatment works and main sewage pumping station therefor. The 2 tank installations adjoin their respective interceptors. Their functions are several—

1. For mingled sewage—storm flows which are less than the capacity of the tanks, to store excess flows so as to permit of a reduced uniform and retarded delivery of storm water to the sewage treatment works.
2. For flows which exceed tank capacity, the tanks furnish a measure of sedimentation and permit the removal of floating matter. Material which is retained in the tanks is returned to the interceptor for delivery to the treatment plant.

The present stand-by tanks are designed to provide 30 minutes detention when the interceptor flow is 8 times the average d. w. f.—in one case for 1945 conditions, in the other and smaller for 1960 conditions.

The storm stand-by tanks near Whittier Street are in three units with an aggregate capacity of 4,011,000 gallons. Each unit is 105 feet long by 187 feet wide. The depth is 12.5 feet − 9.43 feet water depth. The tanks are open and the bottom is guttered at 18-foot intervals to a main center drain which leads back to the interceptor. The bottom of the tanks is set above the (2 times d. w. f.) line of the interceptor for 1960.

The tanks are founded on concrete piles which were designed to resist uplift due to river level (see *Civil Engineering*, **3**, 66). Along the coping walls of the tank, fire fighting equipment is mounted on a movable carriage to enable flushing and cleaning of the tanks.

The storm stand-by tank at Alum Creek is of construction similar to the units for Whittier Street. This installation is, however, in one unit and is covered. Dimensions are: 106 feet by 181 feet 3 inches by 15.25 feet deep—10.25 depth to overflow. The capacity is 857,000 gallons. At this installation forced ventilation is provided by 2 fans which permit of 4 changes of air per hour when the tank is filled to overflow.

Operation and Control of Tanks.—The storm stand-by tanks are brought into use through the operation of regulator sluice gates located in the interceptor and down-stream from the tank inlet connections. The regulator gates are remote-float-controlled from interceptor level, the gates closing and opening according as the flow in the interceptor (to the treatment plant) exceeds or falls below a pre-determined amount. Closing of the gates backs the water up into the interceptor to levels which admit it to the stand-by tanks. Opening of the regulator gates permits the tanks to empty slowly. In the case of the three tanks at Whittier Street the

different units are brought into use successively, thus limiting the fouling of the tanks for small storms.

Additional to the regulator gates are other sluice gates for shutting off the interceptor, for by-passing tanks or for safeguarding them from high river stages. Gate control is automatic and push button. All of the gates are electrically opened by d. c. current from motor-generator sets through storage batteries. The purpose of this particular set-up is to eliminate troubles due to freezing and also those due to failures of current from outside sources. At Whittier Street the storage battery is of sufficient capacity to deliver 40 amperes continuously for 8 hours with a final pressure of not less than 105 volts.

Costs.—Some of the intercepting sewers as described were designed for future construction, but those as built cost, exclusive of engineering, $2,591,000. The regulator chambers cost $351,000. The storm standby tanks cost $679,000. The paper also includes the lengths of intercepting sewers of different size as built, the cost per foot of completed sewer and the average rate of construction progress in feet per day.

FRANK C. TOLLES

Major Sewerage Project for Toronto, Ontario

REPORT BY MESSRS. METCALF AND EDDY AND BY MESSRS. GORE, NASMITH AND STORIE

Canadian Engineer of November 28, 1933 (Vol. 65, No. 26, p. 11) gives a synopsis of a report by consulting engineers upon a major project of intercepting sewers, outfalls and sewage treatment works for the City of Toronto.

Toronto now has a plant (Eastern Avenue) which provides partial treatment. New works are found necessary to furnish capacity and to safeguard bathing beaches and water supply. Further, it is desired to eliminate the present works which have occasioned litigation and allegations of nuisance.

The recommendations of the engineers are that the existing Eastern Avenue plant be supplemented and replaced by a pumping station, and that new works be built at a site 11 miles distant. The plant as proposed would provide complete treatment of the sewage and would include devices and structures for preliminary sedimentation, activation and digestion, and mechanical dewatering of the sludge. All flows up to $2^1/_2$ d. w. f. would be given sedimentation (plus skimming) and all flows up to $1^1/_2$ d. w. f. complete treatment. The plant effluent would be discharged into Lake Ontario in 34 feet of water. Dewatered sludge would be used partly as fertilizer and partly as fill.

The cost of the project is estimated as follows:

Eastern Avenue Pumping Station	$ 859,000
Outfall, pumps to plant	
3500 lin. ft. twin 7 ft. pipe	
56,200 lin. ft. 10 ft. tunnel	9,374,000
Highland Creek Sewage Treatment Works	9,435,000
Outfall, plant to lake	
4480 lin. ft. 9 ft. 3 in. conduit	760,000
Total Plant and Outfalls	$20,428,000
Intercepting sewers—present	5,411,000
Intercepting sewers—future	3,745,000
Grand total	$29,584,000

The program for the plant and outfalls contemplates a six-year construction period with expenditure ranging from $800,000 to $6,000,000 per year.

The improvements which are outlined in the report are intended for a metropolitan development. Toronto city covers an area of 21,755 acres, which accommodates 626,000 people (1930), or about 29 persons per acre. Additional population 166,500 (1930) is found in a number of adjoining urban communities. The forecasts of population for the metropolitan area lead to 1,077,000 people in 1948 and 1,664,000 in 1970. The proposed treatment plant and pumping station are designed for 877,000 people as of 1948, the balance (?) being served by the North Toronto works which apparently are not affected by the plans for other sewerage area.

The outfall to the lake is intended to take all flows up to $2^1/_2$ d. w. f. It would be built in tunnel and would terminate in an uptake shaft with 300-foot diffusion pipes radiating therefrom.

Descriptions of the proposed treatment works are not given in the magazine synopsis nor any of the bases for design. FRANK C. TOLLES

Sewage Disposal by Way of the Illinois River

BY LANGDON PEARSE

Civil Engineering, **3**, 485 (September, 1933)

This five-page paper is an excellent short statement of the progressive changes in a stream which is subject to the influence of large quantities of sewage. The paper also indicates the scope of studies that are appropriate to the problem of the kind indicated.

The Illinois River is the outlet for the sewage of (1930) over 4,000,000 people, and industrial wastes estimated as equivalent to the sewage from

over 3,000,000 people. Nearly 80 per cent of this load comes from the Chicago Sanitary District.

Chicago's contribution of sewage to the river began in 1907. By 1909 changes in river fauna indicated a marked deterioration on the stream, effects being noticed 60 to 70 miles below the city. By 1925 the effects were manifest for 150 miles. Similar results were shown by the D. O. in the river and by data from the fish and mussel industries.

Conditions in the river have developed the conclusions that, where the D. O. falls below 2 p. p. m., fish die overnight. Carp and buffalo fish have been found in waters containing $2^1/_2$ p. p. m., but a variety of fish is found only when 4 p. p. m. or more are present.

Illinois River D. O.'s at various points and for different years are shown in the article by table and graph. The range is from 0.2 p. p. m. to 6.5 p. p. m., with the greater number between 3 and 4 p. p. m.

Conditions in the river began to improve in 1926 in response to several factors, including a cutting down of industrial wastes in 1926 and the starting up of Chicago Sanitary District sewage works in 1928 and 1929. In part, however, this has been offset (1930) by decreased diversion from the lake. The article reproduces diagrams for D. O. and B. O. D. which show the progressive improvement of the river.

Re-aeration is an important element in the control of the river, and this matter is being given study. An example is cited for the Marseilles Dam, some 60 or 70 miles below Chicago, where the pick-up in D. O. during 87 months of observation was 2.85 p. p. m. average, 1.0 p. p. m. minimum and 4.3 p. p. m. maximum, the greatest increase being during the warmer months when the oxygen above the dam was almost depleted.

Also of influence have been variations in time of flow which result from changing conditions in diversions from the lake. Prior to 1933 the 100 mile reach from Lockport to Chillicothe involved a 5- to 6-day period for flows from 8000 to 15,000 c. f. s., whereas under present conditions the period is 7 to 10 days with flows from 5000 to 10,000 c. f. s.

The sewage treatment program of the Chicago Sanitary District now provides for three plants, the (1) North Side, (2) West Side and Southwest Side combined, (3) Calumet.

Since 1930 the North Side plant has been operated to give complete treatment. The average flow is approximately 200 m. g. d. A 5-hour aeration at 0.4 c. f. of air gives an effluent which for the year has an average suspended matter content of 12 p. p. m., and a B. O. D. of 9.7 p. p. m.

The West Side is an Imhoff tank plant. One battery has been operating with West Side sewage only. Another battery has been operating with a mixture of West Side sewage and sludge pumped from the North Side plant. Two experimental, heated, separate sludge digestion tanks have also been operated at these works. Based on yearly averages, the West

Side plant has reduced the suspended solids contents 57.8 per cent, and the 5-day B. O. D. 56.2 per cent. North Side sludge has been digested in varying amounts, ranging from zero to 63 per cent. There has been much test work in the direction of eliminating both sludge digestion and air drying. Extensions of this plant are planned for the activated-sludge process.

The Calumet plant is a smaller sedimentation works which handled about 55 m. g. d. in 1932. Paint wastes have been a problem at this plant. On yearly averages, suspended matter has been reduced by 47–49.5 per cent, and the 5-day B. O. D., by 29–30 per cent. Extensions of this plant are planned for the activated-sludge process.

Conditions in the Illinois River have been the subject of litigation, during which certain standards have been suggested for the maximum permissible pollution. One of these (Howson & Burdick) included the following requirements:

> "The liquid discharged by the drainage canal as evidenced by the averages of representative samples taken from any 30 consecutive days shall (*a*) be practically free from settleable solids deposited in 2 hours, and (*b*) shall contain dissolved oxygen equal to or exceeding the biochemical oxygen demand of said liquid for 5 days when incubated at 20 degrees C., (*c*) shall contain not less than 3 parts per million of dissolved oxygen."

The matter of storm drainage also affects river conditions. Chicago sewers are practically all combined sewers from which dry weather flow and part of the storm flow are intercepted. Overflows occur during periods of storm and on the average about 53 times per year.

FRANK C. TOLLES

Sewage Treatment for Obtaining Park Irrigating Water

BY FRANK MCQUEEN

Public Works, **64**, 16–7 (October, 1933)

Golden Gate Park, covering an area of 1013 acres in San Francisco, is one of the nation's most notable playgrounds.

Sewage from an outfall sewer traversing the park was originally utilized to irrigate the vegetation in the park, but its use was discontinued because of objectionable odors. During the past few years potable water was purchased from the Spring Valley Water Company for irrigation purposes. The excessive cost of this supply resulted in plans by the park commission for converting raw sewage into a suitable medium for irrigation and sprinkling purposes, by means of the activated-sludge process.

The sewage treatment works, completed in 1932, have a capacity for converting one million gallons of sewage per day into clear, odorless water suitable for the purpose intended. The flow in the outfall sewer consider-

ably exceeds a million gallons but only this amount is required for irrigation purposes.

The various elements of the works are as follows:

1. Primary settling basin, equipped with motor driven "straight-line" sludge collectors and scum removing devices.

2. Pre-aeration chamber (which is a section of the aeration chamber) in which the settled sewage from the primary settling basin is given 30 minutes aeration prior to the introduction of the return activated sludge.

3. Aeration chambers (two in series) which are of the Manchester "spiral flow" type. Air, under 2.6 pounds pressure, is introduced through porous tubes set 4′ 0″ below the surface of the sewage in the chambers in narrow channels formed by vertical baffles and one wall of the chambers.

4. Final settling basin equipped with motor driven "straight-line" sludge collectors.

5. Separate sludge digesters, equipped with "straight-line" detritus drags for clearing the two tanks of sand and other inorganic matter.

The digesters are provided with automatic scum and supernatant liquor eductor and a water-sealed gas trap. The gas evolved is metered and amounts to approximately 9000 cubic feet per day. Plans have been prepared to use the gas to operate the pressure blowers and sludge collectors.

6. Sludge drying beds of conventional type for the natural drying of the ripened sludge.

7. Chlorinator and chlorinator basin for disinfecting the final effluent.

Owing to the heavy character of the sewage, 1.95 cu. ft. of air per gallon of sewage are required, including the air required for one sludge lift. The period of aeration is 6 hours, including 30 minutes pre-aeration. The return sludge is not re-aerated, but a small quantity of hydrated lime is added to counteract the effects of the entrained carbon dioxide.

The cost of operating the aeration system, taking electrical energy at 1 ct. per kw. hr., an operator at $125 per month, and lime at 1 ct. a pound and chlorine at 8 cts., but neglecting capital charges, would be approximately $10.60 per million gallons of sewage treated.

SEWAGE TREATMENT ANALYSES (AVERAGE OF 6 MONTHS)

	Raw Sewage	Final Effluent
Total solids	908 p. p. m.	360 p. p. m.
Suspended solids	410 p. p. m.	10–15 p. p. m.
Settleable solids	14.9 cc./liter	
B. O. D.	405 p. p. m.	10 p. p. m.
D. O.		1.7 p. p. m.
pH	7.3	7.3
Relative stability		10 to 30 days

Odors and suspended matter are so completely removed that the excess plant effluent is used for lakes and waterfalls. C. T. WRIGHT

Aerobic and Anaerobic Decomposition of Sewage Solids

BY H. HEUKELEKIAN

Ind. Eng. Chem., **25**, 1162 (1933)

II. Effect of Seeding with Aerated Sludge

Fresh solids were seeded with aerobic sludge developed by the continuous aeration of fresh solids for 90 days. One volume of aerated sludge was mixed with three volumes of fresh solids and the mixture aerated in a glass cylinder fitted with a porous plate. The relative amounts of dry volatile matter used were 7.5 parts of raw to 1 part of seeding material. A 50 per cent reduction of volatile matter was obtained in 35 days of aeration, corresponding to 65 days of aeration required to produce a similar reduction in unseeded material. With seeded material, the fat reduction was 99.9 per cent after 35 days of aeration; with unseeded material an 87 per cent reduction was obtained after 92 days of aeration. It required 70 days of aeration to reduce the total nitrogen of unseeded material 30 per cent. The same total nitrogen reduction was obtained with seeded material in 35 days. The time of decomposition was reduced to half by proper seeding. Under anaerobic conditions, properly seeded sludge decomposes in about the same time as properly seeded aerobic sludge. In the same length of time, the aerobic process gives a more thorough decomposition of organic matter than the anaerobic process.

III. Effect of Reversing the Process after Initial Stabilization

On aeration for 92 days, anaerobic ripe sludge showed a reduction in volatile matter of 42.4 per cent, the protein destruction was 56.5 per cent, fat reduction 61.4 per cent and the B. O. D. reduction 93.0 per cent.

Fresh solids which had been digested for 92 days under aerobic conditions were kept under anaerobic conditions for 34 days. A further reduction of 13 per cent of residual volatile matter and 85 per cent of the fat took place. There was no reduction of organic nitrogen and the B. O. D. increased.

P. D. MCNAMEE

From Disposal by Dilution to Separate Sludge Digestion

ANON.

American City, **48**, 45–6 (Sept., 1933)

Wilmington, Delaware, has recently completed a separate sludge-digestion, sprinkling-filter treatment plant with a capacity large enough to handle the waste of 5000 people. At present only sixty-three houses are

connected to it. The plant is complete in every detail and was built to serve as a full-scale experimental unit for accumulation of data on which future construction in the city will be based.

The sewage passes through a grit chamber on bar screens into the settling tanks. These are equipped with Link-Belt sludge collectors. The effluent flows through two dosing tanks which intermittently dose the revolving sewage distributors on the sprinkling filters. Sludge is pumped to the digesters which are equipped with Downes covers and is finally dried on sand beds.

A face brick office building also houses space for a complete research laboratory. E. HURWITZ

A Sewage Treatment Plant Among Attractive Surroundings

BY E. BENDER

American City, **48**, 43–5 (Oct., 1933)

The sewage treatment plant at Eddystone, Pennsylvania, is located about 100 feet from a main highway and dwellings. Because of this fact stress has been laid toward making the plant attractive visually and otherwise. The town has a population of 2500.

The plant consists of two settling tanks, 12 feet wide by 52 feet long by 10.5 feet deep, equipped with sludge collectors and hand skimming device. All of which are housed in glass inclosed structures; a digestion tank 12 feet by 65.5 feet by 10.5 feet also completely enclosed; six covered drying beds; and pumping station which includes a laboratory and chlorinating room.

The total cost, including site, was $144,500. E. HURWITZ

Renovating a Sewage Disposal Plant

BY P. J. GOODWIN

American City, **48**, 47–8 (July, 1933)

The sewage treatment plant at the Weston State Hospital for the Insane, Weston, West Virginia, was recently completely renovated in order to provide a safe water supply for Clarksburg, West Virginia, which is located down the stream into which the plant effluent is emptied.

New pumps were installed, the Imhoff tanks were repaired and fortified, the original stone on the filter was removed, cleaned and replaced—by institution labor—new chlorinators were installed and the plant land-

scaped. Bacteriological tests show the plant effluent to be of better quality than the water of the stream into which it discharges. E. HURWITZ

Annual Operation Report, Sewage Treatment Works, Springfield Sanitary District Springfield, Illinois 1931 and 1932

BY C. C. LARSON

The report tabulates the average monthly data of operation and analyses for the years 1931 and 1932.

The plant consists of bar screens fitted with mechanical rakes; grit basin of three channels, flow of one foot per second or less; grease removal basin (rectangular tank with double row of filtros plates through center for diffusing air, two longitudinal baffles form a stilling channel for accumulating the grease, and a skimming trough at effluent end; four primary settling tanks; five aeration tanks (retention period 5 hours at 7.5 m. g. d. and 20 per cent returned sludge); four final settling tanks; six sludge digestion tanks; twelve sludge drying beds.

The yearly averages of operation and analyses are tabulated below:

Year	Rainfall, In.	Sewage Flow, M. g. d.	Population Equivalent of Raw Sewage on Basis of 0.14 Lbs. per Capita per Day	5-Day B. O. D. Raw	5-Day B. O. D. Primary Eff.	Sec. Eff.
1931	3.02	6.3	67,975	187	145	14
1932	2.67	7.6	74,268	168	150	17

Raw	Susp. Solids Primary Eff.	Sec. Eff.	Sludge from Primary Tanks: Total Solids, %	Sludge from Primary Tanks: Fixed Solids, %	Air Consumption, Cu. Ft. Air per Gallon of Sewage	Gas Production, Cu. Ft. of Gas per Day
181	98	24	3.25	34.2	1.1	40,648
162	117	21	4.63	45.7	0.91	37,678

The average composition of the gas was CO_2, 31.0 per cent; H_2, 1.7 per cent; CH_4, 64.5 per cent; and N_2, 3.2 per cent.

Average analysis of sludge taken from drying beds was moisture 54.1 per cent, total solids 46.9 per cent, volatile solids 36.1 per cent, nitrogen (as N) 2.07 per cent; phosphorus (as P_2O_5) 1.49 per cent, potash 0.00 per cent; ether soluble matter 4.62 per cent.

The amount of electric power consumed and all cost data are summarized.

H. GLADYS SWOPE

Missouri Water and Sewerage Conference Report of the Eighth Annual Meeting, Sedalia, Missouri

October 13–4, 1932

The papers and discussions on sewage treatment were:

Recent Developments in Sewage Treatment. BY G. R. SCOTT.—The developments discussed are divided into those of equipment, processes and operation. Advancement in equipment is shown by the use of mechanically cleaned screens; mechanisms which constantly remove and wash the grit; grease skimmers; effective sludge pumps; mechanical agitation in the activated-sludge process; revolving arms for distributing sewage over filters; circular tanks with mechanism rotating about a vertical axis tends to break up the sludge and lessens foaming and acid digestion in the digestion tanks.

New developments in sewage treatment processes are those of incineration of screenings and of sludge; chemical precipitation as shown by the Laughlin process at Dearborn, Michigan, and the use of chemicals for relieving overloaded plants; and pre-aeration of sewage.

The greatest advance in operation is the demand for efficient and orderly operation.

Laboratory Control of Sewage Treatment Plants. BY RALPH E. FUHRMAN.—Stresses the importance of laboratory tests for control, and the value of such records. Tests for a plant vary with size of the plant and completeness of treatment.

The Collection of Gas for Heating Sludge. BY George S. Russell.—As bacterial action proceeds best at temperatures above 70° F. it is wisdom to heat the digestion tanks and it is economy to do so by using the gas produced from the digesters. The most advantageous place for the heating coils is between the supernatant liquor and the well-digested sludge.

Prechlorination of Sewage for Odor Control. BY G. C. FOX.—There are two Imhoff tank plants in Marceline, Missouri, both of which had complaints from odors. In the larger plant the influent was chlorinated at a junction of trunk lines adjacent the plant. The most satisfactory arrangement was obtained at the smaller plant when the chlorinator was moved up stream to a junction of two trunk lines 1500 feet above the plant. Amount of chlorine used varied with the weather conditions, more being used during the hot weather.

The Power Cost of Activated-Sludge Treatment. BY HUGH BROWN.—Tabulates the power cost per month for 1931 and 1932, and the amount of sewage treated, using Simplex aerators.

H. GLADYS SWOPE

The Logical Design of Separate Sludge Digestion Plant and Its Effect Upon Other Phases of Sewage Treatment

BY A. S. LOWE

Presented at a Conference of the Institute of Sewage Purification held at the Public Works, Roads and Transport Congress, November 17, 1933. Résumé in *The Surveyor*, **84**, 478 (Nov. 24, 1933).

The author ascribes the slow progress of separate sludge digestion in England to the successful open tank procedure developed at Birmingham, which has been closely followed at other plants.

Optimum conditions for sludge digestion with methane production are set forth as (1) temperature 80° F., (2) pH 7.0 or over, (3) low moisture content, (4) fresh raw sludge introduced in small amounts with the necessary quantity of digested sludge.

Disadvantages of Open Tanks.—The above conditions cannot be maintained in open rectangular tanks of considerable area in that in winter temperatures of 80° F. cannot be maintained and digestion is retarded, layers of water form at various depths which prevent thickening of the sludge and intimate mixing of raw and seeded sludge is not possible. Other objections are the formation of scum surfaces which interfere with gas production and sludge digestion, formation of banks of inert material and the expense of gas collection by floating covers. Such tanks are costly, moreover, because from 5 to 8 cu. ft. per capita must be provided and operation is expensive and uncertain.

Heated Tanks.—To maintain the proper digestion temperature of 80° F. heat may be applied to the sludge either before or after it enters the tank. Heating coils in the tank are generally favored in Germany and America and, if the water circulated in such coils is not over 120° F., the coils will not cake with sludge on the outside. Ordinary galvanized iron pipe has been found best.

Deep, circular tanks with covers are most economical for sludge digestion and at the same time provide efficient mixing of the raw sludge, introduced at the top, and digested sludge, by means of the gas generated in the digesting sludge, which rising to the top, carries with it particles of the seeding material. Additional mechanical mixing or vertical circulation such as practiced in Germany is of doubtful value, except perhaps in starting a new tank. Such tanks are suitable also for installation and operation of thickener mechanisms for prevention of layers of water and of surface scum formation. For this latter purpose horizontal arms, attached to the vertical shaft, revolve just beneath the sludge level, which is maintained against the under side of the cover.

Capacity of Heated Digestion Tanks.—The rate of reduction of dry volatile matter by digestion at 80° F. is shown in the form of a graph, from which the following readings are obtained:

Digestion time in days, 80° F.	0	5	10	15	20	25	30	35	40
Weight of volatile matter in lbs.	1.0	0.93	0.79	0.58	0.48	0.42	0.39	0.38	0.37

Another graph illustrates the effects, both of digestion and of thickening, upon the volume occupied by volatile and inorganic matter. By use of these graphs, the theoretical capacity of the digestion tank may be calculated, knowing the amount of solids and the percentage of contained volatile matter to be received daily. From the results of examples the author concludes that where proper facilities are provided for obtaining the sludge in the best condition 0.75 to 1.0 cu. ft. capacity of heated digestion tank per capita is sufficient. Higher capacities found in practice are probably due to provision for increases in population, high moisture content or septic condition of the sludge or improper methods of adding fresh sludge to the digestion tank.

Sedimentation in Relation to Digestion.—The author states that mechanically the sludge tanks will thicken sludge to 92 or 93 per cent water and therefore produce the best material for separate sludge digestion and in addition are cheaper.

Screenings, Detritus and Humus.—Nuisance resulting from screenings and detritus may be prevented by removing all contained putrescible material and returning it to the sludge. This may be readily accomplished by washing the screenings by a high-pressure water jet and passing the detritus through a washing machine combined with the elevating mechanism. Humus sludge and excess activated sludge are also returned into the sewage flow and eventually reach the sludge digestion tank from the sedimentation tanks.

Gas Collection.—The fixed roof on the digestion tank is now preferred to the early type floating cover. With proper operation, and especially if the gas holder is properly connected, no danger of creating an explosive mixture exists through drawing air into the tank when sludge is withdrawn rapidly.

Heat Requirements.—Heat must be provided to raise the temperature of the incoming sludge, a comparatively negligible proportion of the total requirement, and to replace radiation losses. This radiation loss in a tank with 12-inch concrete walls in dry excavation half its depth and banked with earth around the upper half may be taken at about 6 B. t. u. per sq. ft. per hour. If the tank is constructed in saturated ground this

loss will be considerably greater. Heat may be obtained from the cooling water of engines using the digestion gas, which will permit recovery of about one-third of the heat value of the gas thus consumed. When used in this way, approximately 400 cu. ft. of gas per day will produce 1 British horse power continuously on the engine shaft.

Incineration of Screenings.—Sludge gas is especially suitable for incineration of screenings which, because of their high moisture content, are exceedingly difficult to burn. A self-supporting flame of considerable intensity is necessary as well as a specially designed furnace with lining protected against the high moisture content of the gases of combustion.

Results from Heated Digestion Tanks.—The results from 17 sludge digestion plants using heated tanks, equipped with thickening mechanisms, are given as follows:

	Average	Maximum	Minimum
Capacity, Per Capita	1.5	2.3	0.9
Moisture in Raw Sludge, Per Cent	95	98.5	91
Temperature of Digester, ° F.	86	96	70
Per Cent Reduction in Volatile Matter	56	74	30
Gas Per Capita, Cu. Ft.	0.827	1.25	0.5
Calorific Value of Gas in B. t. u.	660	750	600

J. K. HOSKINS

Recent Developments in Methods of Sewage Works Analysis

BY JOHN T. THOMPSON

Presented before the Public Works, Roads and Transport Congress, Nov. 17, 1933

The author relates the slow progress in Great Britain of standardizing methods of analysis of sewage and sewage works effluents, reviews the widely variable results obtained with the biochemical oxygen demand test and the more recent recommendations by various workers in Europe and America for improvement of the procedure and then presents comparable analytical data of the modified Miller test and the Royal Commission (R. C.) (Rideal-Stewart Winkler) method from which he concludes the former is more reliable.

The extensive precautions and modifications necessary with the Winkler method are so cumbersome that for sewage works operators the simpler Miller method is to be preferred. Specific disadvantages of the R. C. test are:

1. For the dissolved oxygen determination so many active reagents are used that results are inaccurate because of the complex mixture of unstable substances in sewage.
2. For estimating B. O. D. the incubation period is too long for prac-

tical purposes and accuracy is sacrificed if the incubation temperature is raised. Large errors are likely to occur if the dilution water is not carefully standardized.

The Modified Miller Method of D. O. Determination

This test is based upon the oxidation of an alkaline solution of ferrous hydroxide tartrate complex by the dissolved oxygen, the end-point being indicated by the reduction of methylene blue to a colorless solution.

Reagents.—1. Alkaline tartrate: 350 grams pure Rochelle salt and 100 grams pure caustic soda in 1 liter of water.

2. Ferrous ammonium sulphate: 10.75 grams of the pure salt and 10 ml. pure sulphuric acid per liter, this stock solution diluted with an equal volume of air-free distilled water, that is, 5.375 grams of salt per liter for use in the titration. It should be previously standardized against water of known oxygen content.

3. Indicator solution: 1 gram methylene blue per liter.

Procedure.—Place 50 ml. of the clear or settled sample in a 100-ml. Nessler tube, care being taken to avoid aeration, and protect the surface from the air by a 3-ml. layer of pure paraffine oil. Add 2 drops of methylene blue and 5 ml. alkaline tartrate solution. Titrate with the ferrous ammonium sulphate solution through a burette protected from aeration and fitted with an elongated tip extending below the paraffine seal of the Nessler tube, the liquid being stirred meanwhile with a bent glass rod. The end-point, when the blue color is discharged, is quite sharp. The milliliters of ferrous ammonium sulphate (5.325 grams per liter) multiplied by 2.5 give the oxygen in solution in parts per million.

This procedure is not affected by the presence of sulphates and nitrites as demonstrated by the results of comparative tests presented by the author, from which he concludes that sodium sulphite, sodium nitrite and iron alum up to a concentration of 200 p. p. m. do not interfere with the dissolved oxygen determination. On the other hand, the R. C. (Rideal-Stewart) method gives low results with 25 p. p. m. of sulphite, irregular results with over 50 p. p. m. of sodium nitrite and an apparent increase in the presence of ferric salts. The straight Winkler method is useless when these compounds are present in the sample.

Estimation of B. O. D. by Using Oxygen

The author holds that the B. O. D. of an effluent or river water can be determined more promptly by saturating the sample with oxygen than by diluting it with water which is saturated with air. Also the saturation value of pure oxygen in water is nearly five times that of oxygen and nitrogen together, so that if the sample is saturated with oxygen only, a suf-

ficient supply is provided without the necessity of dilution which might affect the biochemical reaction. The recommended procedure is to bubble pure oxygen through a series of small bottles of the sample for about 10 minutes, during which period the dissolved oxygen will reach about 39 p. p. m., determine the D. O. in one portion, incubate the other portions for the required time and determine the oxygen remaining at the end of the incubation period. The author has used regularly the 24-hour incubation period at 18.3° C. and presents a series of B. O. D. analyses, comparing the R. C. (dilution 1 to 4) method with the modified Miller method for periods of incubation from one to seven days. The results of the R. C. method are generally the higher and more irregular, although in the case of samples of high B. O. D. the ratio is constant. The author concludes that more reliable results are obtained with the Miller method than with the R. C. 5-day incubation procedure, using aerated tap water for dilution.

Other Recent Research on Analytical Methods

The work of Dr. Lloyd (*Jour. of Hyg.*, **33**, 183, 1933) is briefly summarized in which he has found that a culture of the protozoön *Polytoma Uvella* may be of value in determining the oxygen content of liquids. Tubes 60 mm. long and 4 mm. bore are inoculated with 0.1 cc. of this organism and certain motile bacteria and to this inoculum a depth of 40 mm. of the sample to be tested is placed. The protozoa leave the inoculum moving upward through the sample at a rate dependent upon the available oxygen which they use up as they climb, so that the less dissolved oxygen present the more rapidly they ascend. J. K. HOSKINS

The Disposal of Surplus Activated Sludge

BY H. D. BELL

Presented before the Public Works, Roads and Transport Congress, Nov. 17, 1933, and abstracted in *The Surveyor*, **84**, 513 (Dec. 1, 1933).

Further studies on the dewatering of activated sludge, originally reported in a previous paper (see THIS JOURNAL, **5**, 174-7), are presented by the author of the new process. Based on the results of extended research, the theory was advanced that sharp and rough surfaces of certain inert materials attracted the light, solid particles of activated sludge, producing coagulation and a separation of a comparatively large proportion of the supernatant liquor and that smooth and rounded surfaces of certain other materials was found to have an attraction for moisture present in other types of sludge, which, if used in the top layer of a drying bed, would cause the sludge to dry more rapidly.

In practice, the author has found that where the surface of a drying

bed is a sharp ash the sludge invariably adheres, whereas on a bed of smooth grained sand it does not. Therefore, in using beds with a top layer of smooth, rounded grained sand, he dusts them over lightly with sharp ash before applying the sludge, so that on removal of the dried material the surface of the bed remains intact.

Experiments having established that it was possible to separate up to 65 per cent of the supernatant liquor activated sludge by mixing it with an inert material having a rough surfaced contour, a new plant involving this procedure was placed in operation in August, 1932, since which date it has handled the surplus sludge from a $^1/_2$ m. g. d. bio-aeration unit at Barnsley. This plant for partially dewatering activated sludge is essentially a mixer and a tank for settlement. Coagulating materials such as clay, clinker ash, sand, crushed stone and burnt sludge ash are fed from a hopper by means of a worm-conveyor to the surplus activated sludge passing through the mixer to the settling tank. After settling for a half-hour the supernatant liquor is drawn off through a floating arm. Operating data for four months show that a total of 3677 tons of activated sludge containing 99.37 per cent water were dealt with and that by applying 33.7 tons of dry coagulant the bulk of sludge was reduced 69.6 per cent by weight, or 71.9 per cent by volume.

Application of this concentrated sludge on an experimental drying bed with a surface layer of smooth, rounded sand grains has produced a residue with a moisture content of 80 per cent in five days during showery weather. Even on the dump, following removal from the drying bed, moisture continues to leave the partly dried sludge and, within twenty days, as low as 70 per cent moisture was recorded. From these experiments it appears that 1152 square yards of bed are sufficient to handle the coagulated sludge from the 500,000 gallons of sewage per day, equivalent to an area of one square yard per annum per each 19 persons, in contrast to the previous area of 3 acres which was found to be insufficient. New drying beds are to be constructed on this principle, the drainings and surface liquor from which beds will be passed on to the land and mixed with the soil.

In practice with the new plant, the average proportion of coagulant to dry solids in the activated sludge is 59 to 41 or 92.2 lb. of coagulant per 1000 gallons of sludge, whereas in the laboratory experiments from 62 to 65 per cent of the dried deposit consisted of coagulant. Further study is being given to the dilution of the nitrogen content effected by the addition of coagulants and to the possibility of compensating for such loss by substitution of a phosphate through the use of a basic slag or other similar material as the coagulating medium. Increased fertilizer value of the finished product would be obtained by this procedure.

J. K. HOSKINS

Keeping Our Streams Clean

Civil Engineering, **3**, 493

Under this general title are presented three separate papers which deal with particular phases of the stream pollution problem. These are given under separate titles and with authors as shown below.

Problem of Stream Cleansing

BY ALMON L. FALES

The pollution of streams may have effect upon: (1) health, (2) comfort—sensory effects, (3) industry, including fisheries, and (4) navigation.

Self-purification of streams, once relied upon rather blindly but now more definitely evaluated and delimited, is accomplished by subsidence of solids in pools and also aerobically through demands upon the dissolved oxygen in the water. Oxygen is derived from the atmosphere and agitation is an effective aid. The avoidance of putrefactive conditions requires meeting or exceeding a critical ratio between oxygen demand and oxygen supply.

Streams themselves may be improved by storage as in the case of certain artificial lakes in Germany. Chemicals have also been used, *e. g.*, nitrate of soda, chloride of lime, and, through sewage plant effluents, liquid chlorine.

The improvement of streams through pre-treatment of the wastes which are discharged into them is accomplished often by the usual processes of sewage treatment or as modified, but sometimes by radically different methods wherein the recovery of by-products is a factor.

The degree of treatment required for industrial wastes is determined by the character of the stream, the extent of dilution and the subsequent use of its waters. Even with adequate dilution, consideration must be given to dispersion and the correlative effects of temperature, winds, tides and currents. Tidal waters introduce special problems. The tidal prism adds to the run-off which is normally available for dilution, but flood tides promote sedimentation and, where the prism is long, final passage to the sea may be delayed. Sea water also aids in the precipitation of fine solids and increases the formation of hydrogen sulphide. Likewise, because of changing levels, it facilitates the liberation of gas.

To support fish life, the dissolved oxygen must be not less than 3 p. p. m. Recreational waters should be free from discoloration. Waters for bathing should be free from visible pollution and, although there is no bacteriological standard for such waters, they should be reasonably free from bacteria of sewage origin.

For sources of water supply, the U. S. Public Health Service studies of

the Ohio River indicate a maximum *B. coli* index of about 5000 per 100 cc. as permissible, but also that with certain combinations of water purification it might be possible to cope with raw water having an index as high as 60,000 per 100 cc. However, a bacteriological standard is not the sole measure as evidenced by the fact that Treasury Department standards for the potable waters of common carriers include the elements of protection and physical and chemical characteristics as additional to those of bacteriological quality.

Funds obtainable under the terms of the National Industrial Recovery Act, together with outright grants permissible thereunder, are directly available for projects involving the "conservation and development of natural resources" including "purification of waters."

Relative Importance of Industrial Wastes in Stream Pollution

By L. F. Warrick

Rapid expansion of industry has brought in its train pollution of streams and problems of waste disposal.

Although there is popular demand for clean streams and also legal warrant for the recovery of damages where waters are impaired in quality, there are technical and economical considerations which must be given weight in the problem of stream betterment. A number of Government agencies have undertaken investigations which look to minimizing the discharge of wastes and to improving the character of surface waters. Examples of these are the Sanitary Water Boards of Pennsylvania and Illinois, the Michigan Stream Control Commission, the Ohio River and Great Lakes Board of Public Health Engineers, and the U. S. Public Health Service. Industry is also participating in the problem as evidenced by such organizations as the American Pulp and Paper Association, and the American Petroleum Institute.

The general policy which guides the various programs of investigation and correction involves: (1) utilization of wastes and (2) correction of residual pollution. In certain cases, *e. g.*, pulp and paper and corn products, the utilization of wastes has not only reduced the pollution problem but has more than paid for itself. In this direction, it is sometimes advantageous to segregate different wastes within an industrial plant.

Different agencies have different views of stream pollution effects and of the relative responsibility of causes therefor. Accordingly, a good pollution yardstick is necessary. This may be either biochemical oxygen demand, solids or other element, but in any case must be reflective of the subsequent use of the stream. No one unit suffices, as is shown by Wis-

consin studies upon fish life. Thus it appears that fish may be affected in one or in several ways: (1) by toxic effects, (2) by changes in water conditions, affecting the fish themselves or their food supplies, and (3) through interference upon reproduction or upon young fish. Similarly, it is stated that, although the sulphite and sulphate pulp mill wastes are both toxic to fish in dilutions less than 1 part in 200, by volume, the sulphite wastes in their greater avidity for oxygen probably influence fish life in dilutions greater than that of toxic effect. Effects upon fish food or reproduction are not so susceptible of present measurement.

The offensiveness of industrial wastes is best determined by oxygen demand, whether biological, chemical or both. While there are cases where B. O. D. may be misleading, advances in technique may be relied upon to render this method dependable. However, a particular need is for studies which will make the work of different laboratories comparable.

The effect of industrial wastes is sometimes converted into terms of domestic sewage, either the waste materials or raw products of industry being used as one factor. Thus, if domestic sewage has an average oxygen demand of 0.167 pound per capita per day, the following wastes or raw materials are equivalent to the populations as given:

Type of Plant	Unit	Population Equivalent
Paper Mills	Ton of paper	30.5
Sulphite Pulp and Paper Mills	Ton of paper	1600.0
Groundwood Pulp and Paper Mills	Ton of paper	19.7
Kraft Pulp and Paper Mills	Ton of paper	332.0
Sulphite Pulp Mills	Ton of pulp	1650.0
Groundwood Pulp Mills	Ton of pulp	39.7
Kraft Pulp Mills	Ton of pulp	393.0
Condensery	1000 lb. of milk intake	4.8
Cheese Factory	1000 lb. of milk intake	16.1
Milk Receiving Station	1000 lb. of milk intake	2.8
Milk Bottling Plant	1000 lb. of milk intake	4.7

Certain trade waste pollutions which affect the palatability of water supplies should be corrected with a minimum of delay, in order to avoid driving consumers to other waters of questionable purity. Phenols are an instance in that in quantities as small as 1 part per billion they are reported to cause tastes and odors in water supplies treated with 0.5 p. p. m. of chlorine.

Decatur Cleanses the Sangamon River

BY W. D. HATFIELD

The Sangamon River has a length of about 55 miles between the City of Decatur and the water works intake of Springfield. For one-third of its length the river is canalized, the balance consisting of alternate pools

and riffles. Sanitary surveys in 1912–13 showed gross pollution of the river below Decatur, normalcy being restored some 15 or 20 miles below the city. Surveys in 1918–19 showed pollution effects 30 miles below Decatur, and during severe winter conditions showed pollution at Springfield.

In 1924 Decatur put into operation sewage treatment works for 60,000 people. The original works consisted of Imhoff tanks, sprinkling filters and secondary tanks (see *Trans. Am. Soc. C. E.*, **94,** 544). Phenomenal growth in local starch and glucose works contributed wastes with a population equivalent of more than 300,000 and led to the addition of a partial activated-sludge treatment between the Imhoff tanks and the sprinkling filters. This was done in 1927 and was coördinated with changes in the starch industry which resulted in a reduced wastes load. Further, in 1930, the plant was supplemented by a pumping station for the final effluent and thus to permit of the year-around operation of sprinkling filters the operation which had previously been subject to river stages. Again, in 1932, the works were supplemented by a storm water tank designed to afford 30 minutes detention of storm flows up to a total of 4 times the dry weather flow. A separate heated sludge digestion tank was installed for the digestion of storm water sludge and to relieve Imhoff tanks.

The works, as now constituted, provide all year around complete treatment of dry weather sewage and of storm flows up to 4 times the average. The treatment removes from 90–95 per cent of the B. O. D. and the bacteria, and produces an effluent which contains between 10 and 20 p. p. m. of B. O. D. and 5 p. p. m. of nitrates.

During years of normal rainfall the Sangamon River at Decatur has a given run-off, but during dry periods, as evidenced by the drought years of 1931–32, the flow in the river at Decatur is very restricted and consists predominantly of 10 m. g. d. of sewage plant effluent.

Sanitary surveys have been made of the stream between Decatur and Springfield since, prior to the construction of the treatment works. Originally, D. O. and B. O. D. were the only determinations, but these were supplemented later by counts of total bacteria and by presumptive tests for *B. coli.*

Results from the series of surveys are shown in the original paper by diagrams which portray the different determinations at different points downstream. These data show the gross pollution of the stream in 1926 and the changes therein as responsive to following improvements in sewage treatment. During the worst conditions of 1926, the maximum B. O. D. in the river was 168 p. p. m. with rapid improvement downstream. Except at highest river elevations, a positive oxygen balance was not reached for 15 or 20 miles below the plant. The surveys showed generally foul conditions in the river for from 15 to 30 miles. During this period treatment was such that the population equivalent of the plant effluent varied

from 150,000 to 250,000, while river flows varied between 50 m. g. d. and 225,000 m. g. d.

River surveys were continued during succeeding years. The paper presents certain comparative test data in diagram form. The following table portrays the figures so shown.

SANGAMON RIVER

SANITARY SURVEY DATA—VARIABLE CONDITIONS OF RIVER FLOW AND SEWAGE TREATMENT

	Low River Stage		High River Stage	
Date	Sept., 1927	Apr. 9, 1931	Feb., 1932	Dec. 29, 1928
Sewage Treatment	Sewage By-passed	Plant in Operation	Sewage By-passed	Plant in Operation
River Flow	7 m. g. d.	20 m. g. d.	500 m. g. d.	500 m. g. d.
Temperature, ° C.	19 deg.	18 deg.	3 deg.	2 deg.
Population Equivalent of Effluent	150,000	11,000	88,000	43,000
Total Bacteria/Cc.:				
At Outlet	1,000,000	70,000	20,000	30,000
55 Miles Down	5000	500	5000	1000
B. coli/Cc.:				
At Outlet	1,000,000	2000	10,000	15,000
55 Miles Down	100	1	100	10
B. O. D.:				
At Outlet	15 p. p. m.	5 p. p. m.	3 p. p. m.	1 p. p. m.
55 Miles Down	4 p. p. m.	4 p. p. m.	3 p. p. m.	1 p. p. m.
Oxygen Balanced	30 mi. down	6 mi. down	Throughout	Throughout

(NOTE: Tabular values were read in part from logarithmic diagrams and the values given are intended only to portray the general conditions.)

The curve data are interpreted to show (*a*) the effect of the sewage works, (*b*) the results of high water in carrying pollution downstream and (*c*) the influence of low temperature in maintaining a biological and bacterial status.

Storm overflows from combined sewers during periods of low water were also factors of pollution. In a given case when the flow was 3 to 10 m. g. d. the river water contained but 6 p. p. m. D. O. and fish were killed or stunned.

Biological surveys of 1918 and 1919 showed that under the conditions then fish could live only in high water and that bottom flora and fauna were typically pollutional. A flood of 1926 scoured the river and additional cleansing resulted from high water of 1927. In 1928 (after pre-aeration was instituted) bottom life was normal. Also healthy fish were found in nine varieties. In 1929 a fish count showed additional varieties and increased numbers, the greatest count being found below the sewage treatment works.

FRANK C. TOLLES

California Regulates Use of Sewage on Crop Land

Public Works, **64**, 10 (Oct., 1933)

Under California's public health act, the disposal of sewage, sewage effluent or sludge for irrigation or fertilizing purposes is permitted only to those who hold a permit issued by the State Board of Public Health, and subject to regulations adopted by that board on May 27, 1933. Under these regulations:

Raw sewage shall not be used for irrigating growing crops.

No sludge or screenings can be used for fertilizing any growing vegetables, garden truck or low-growing fruit or berries, unless it has been kiln-dried; dried on beds or aged by storage for at least 30 days; conditioned or aged to the satisfaction of the State Health Department; or digested to a point where it is practically odorless, drains readily and contains not over 50 per cent of the total solid matter in volatile form.

Effluents of septic tanks, Imhoff tanks or other settling tanks, or partially disinfected effluents of sprinkling filters or activated-sludge plants shall not be used to water any vegetables, berries, fruit, etc., which could come into contact with it, even as windfalls; nor shall sewage, effluents, sludge or screenings be permitted in ditches or pipes used for irrigating such crops. However, such effluents may be used on nursery stock, cotton, and such field crops as hay, fodder corn, cowbeets, etc., provided no milch cows are pastured on the land while it is moist with sewage.

These restrictions do not apply to well-oxidized, non-putrescible and reliably disinfected or filtered effluents which meet the following standard: In any 20 consecutive samples, from which five 10-cc. portions each are examined, not over ten portions shall be positive for members of the coli-aerogenes group, and in no single sample shall over half the 0.1-cc. portions be positive for them. Disinfecting equipment must be in duplicate throughout, and installed in a room separate from that in which the disinfecting agent is kept, and warmed to prevent freezing; the sewage flow must be measured and the disinfectant applied in excess of actual need, which shall be checked by laboratory tests at least twice daily.

C. T. WRIGHT

The Maryland-Delaware Water and Sewerage Association

Proceedings, Sixth Annual Conference, 1932

Elementary Sewage Disposal. LEWIS V. CARPENTER.—A brief history of the art of sewage disposal from the time of Hammurabi and Moses. The function of screens, grit chambers, settling tanks and oxidation processes; and methods of sludge disposal are briefly reviewed.

A discussion and tabulation of the various treatment plants in Maryland is given by George L. Hall.

Admission of Industrial Wastes Into Sewerage Systems. H. M. FREEBURN.—Whether or not an industrial waste should be allowed to enter a municipal sewage plant depends upon the case in hand; however, there are certain general rules which can be summarized as: (1) Industrial wastes which simulate domestic sewage as to characteristics and rate of flow can be admitted to the sewage treatment plant without harm. (2) Wastes, which are intermittent but which do not differ materially from ordinary sewage, can be taken care of at the treatment works if the flow is equalized. (3) Industrial wastes having the following characteristics should be given preliminary treatment before discharge into the sewers: wastes which contain substances that will form deposits in the sewers or adhere to the invert and sides; those containing excessive amounts of fats or oils; acid wastes; wastes a great deal stronger than raw sewage; those having a high solid content; those with offensive odors; and wastes having an inhibitive effect on bacterial and biological activity. (4) Live steam, scalding liquids, illuminating gas, exhaust gases, gasoline, oil and strong acid wastes should be excluded from the sewerage system.

Mr. J. B. Gordon discussed the paper by giving a report of difficulties Washington, D. C., had encountered in the deterioration of a concrete sewer due to the discharge of wastes from a yeast plant, these wastes having an average temperature of 81° F., sulphate content of 78 p. p. m. SO_3, high bacterial content and 0.2 p. p. m. of hydrogen sulphide.

Symposium—Control of the Pollution of Streams. Procedure in Delaware. R. C. BECKETT.—In this state only two streams are used as a source of public water supply—the Brandywine Creek and Naaman's Creek. The pollution at Naaman's Creek is local in character and is due to several large piggeries. Brandywine Creek has three typical sources of pollution; sewage from towns and isolated dwellings, industrial and trade wastes (paper mills, oil, steel mills, laundries, gas house, ice plants) and washings from soil, manure, barn yards, etc.

A complete survey of the Brandywine Creek was made by Dr. Willem Rudolfs for the Board of Water Commissioners at Wilmington, and is abstracted in THIS JOURNAL, **4**, p. 403.

The most outstanding results secured in reducing the load on this stream, as far as the State of Delaware was concerned, was the installation of savealls at one industrial plant and the construction of an outfall sewer jointly by the City of Wilmington and the E. I. DuPont de Nemours and Co., for the purpose of carrying away the varied chemical wastes from the experimental station, as well as the effluent from the small sewage treatment plant. In Pennsylvania, the chief improvements were the construction of sewage treatment plants at Coatesville, Downingtown and West

Chester. Several paper mills either installed save-alls or treated their wastes.

Procedure in Pennsylvania. W. L. STEVENSON.—The main river systems are the Delaware, Susquehanna, Ohio, Monongahela and Brandywine Creek. There are 240 sewage treatment plants, and 700 water works, supplying 83 per cent of the population.

The Sanitary Water Board was formed in 1923 with power to do investigatory work. Three policies were adopted: (1) classification of waters in the state so that clean streams will be maintained for enjoyment and water supply purposes; (2) coöperation with municipalities, industries, health authorities of neighboring states; (3) general hierarchy uses of water, so that public water supply is paramount.

For six years scientific surveys have been made of the rivers of the state and many of their tributaries. Mobile laboratories are used for these investigations. Automatic gauging stations are used for recording stream flows. The surveys deal with the sanitary quality of the water and the kind, character and amount of pollution. Studies of the rivers are made in warm weather, when the stream flows are at normal rate or below. At other times studies are made of the industrial wastes discharged to the river.

Coöperation between municipalities and the state is secured by making a comprehensive sewerage plan, which is submitted to the Sanitary Water Board for approval; then a reasonable length of time is allowed for construction of the essential parts of the sewerage system, compatible with the urgency for need of abating pollution and the financial ability of the municipality; a progressive program of construction is formally proposed by the municipality; and finally the state authorities assist the local officials in developing favorable public sentiment for providing funds for the project.

Formal agreements are relied upon for finding reasonable and practicable ways and means for industrial waste treatment.

A "Tannery Waste Disposal Committee of Pennsylvania" was created in 1925. The tanneries coöperated with the state and six years were devoted to laboratory research and the operation of two full-scale experimental treatment works in 1930.

In 1926 the "Pulp and Paper Waste Disposal Committee of Pennsylvania," consisting of 13 technical representatives of the industry and two of the state, with the chief engineer of the Sanitary Water Board as chairman, was formed. Research was conducted at 8 large paper mills and state engineers made investigation of the streams below the mills. "Save-alls," such as various kinds of fine screens and settling tanks with and without the use of chemical precipitants, were studied and improvements and new ones were made.

The Sanitary Water Board in 1928 made an agreement with all companies operating by-product coke ovens in Pennsylvania whereby the companies were obligated to maintain and efficiently operate apparatus for the elimination of the substantial treatment of their waste and odor producing waste waters. Also a downstream waterworks must be notified immediately of a "spill."

In 1928 an agreement was made with the producers of manufactured gas similar to that for the by-product coke industry and the same good results were obtained, as the industry has quite generally installed means for restraining their tarry wastes.

The "Bituminous Coal Mine Drainage Board of Pennsylvania" was formed in 1929 to stop or retard acid mine drainage.

The "Ohio River Board of Engineers" was formed to protect the drainage basin of the Ohio River and its tributaries from undue pollution, and for protection of water supplies. This has resulted in friendly coöperation with the adjoining states.

Procedure in West Virginia. E. S. TISDALE.—A comprehensive stream control act was passed in June, 1929. The administrative units combined to enforce this law were those of public health, power and recreation and fish and game. A trained chemical engineer was appointed to do the field work and make pollution investigations. Coöperation with industries has been secured and research is financed jointly, if desirable. Research may be carried on at the state university. Coöperation with municipalities has not been satisfactory so far.

Procedure in Maryland. ABEL WOLMAN.—In 1912 and 1914 the state passed a very comprehensive public health act. The State Board of Health is the single agency which has the power to control all problems relating to domestic sewage, industrial wastes, stream pollution, water works and fish and game regulations. This concentration of authority cuts down expenditures and "red-tape" and is highly efficient.

H. GLADYS SWOPE